ELECTRICAL ENGINEERING

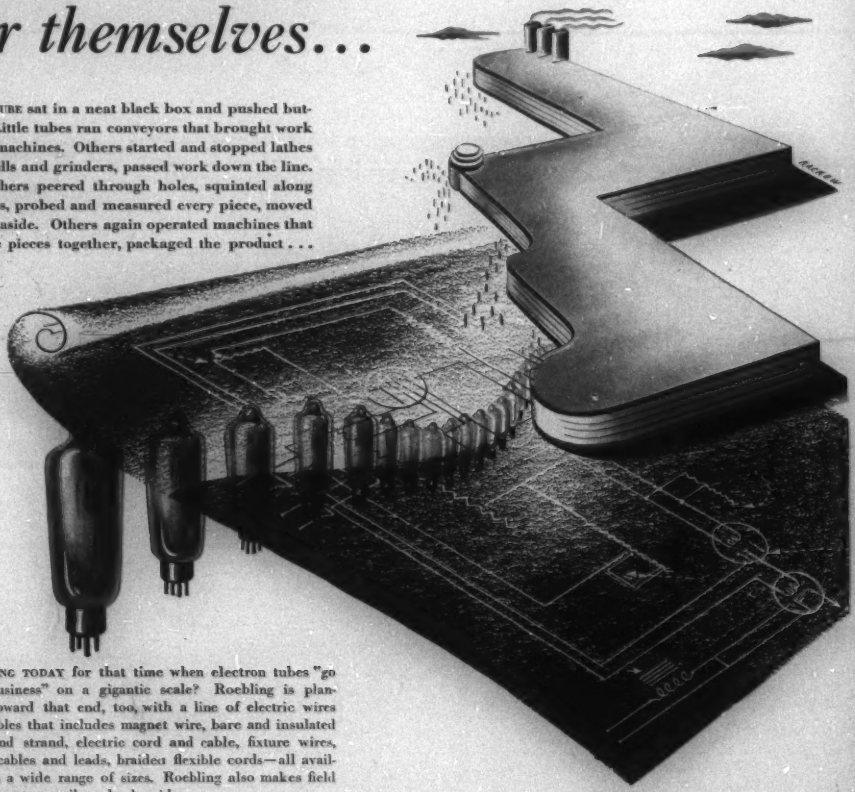
JANUARY 1943

AIEE NATIONAL TECHNICAL MEETING, NEW YORK, N. Y., JANUARY 25-29, 1943

Vol. 62
1943

In 194X... a family of electron tubes will go into business *for themselves...*

A BIG TUBE sat in a neat black box and pushed buttons. Little tubes ran conveyors that brought work to the machines. Others started and stopped lathes and drills and grinders, passed work down the line. Still others peered through holes, squinted along surfaces, probed and measured every piece, moved misfits aside. Others again operated machines that put the pieces together, packaged the product . . .

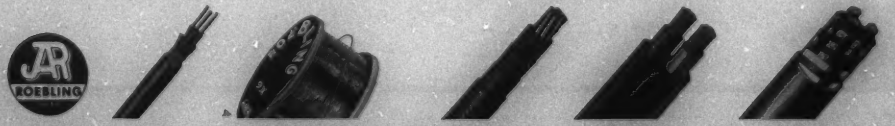


PLANNING TODAY for that time when electron tubes "go into business" on a gigantic scale? Roebling is planning toward that end, too, with a line of electric wires and cables that includes magnet wire, bare and insulated wire and strand, electric cord and cable, fixture wires, brush cables and leads, braided flexible cords—all available in a wide range of sizes. Roebling also makes field coils, armature coils and solenoids.

More than this, though, Roebling is equipping and manning today, toward the production of new types of electric wires and cables as these are required by the growing electronics industry and the electrical industry as a whole. For your needs of today and your plans for tomorrow, you can rely on Roebling as your source for everything in electric wires.

JOHN A. ROEBLING'S SONS COMPANY
TRENTON, NEW JERSEY — Branches and Warehouses in Principal Cities

ROEBLING
ELECTRIC WIRES AND CABLES



A FEW OF THE MANY BELDEN PROCESS INSPECTION TESTS

This Die Lubricant Test

checks the fat content of coolants used in Belden wire-drawing machines

Agitator tank supplying emulsion to dies.

Process inspection of wire passing through die.

Magnet wire is produced by drawing copper rod at high speed through tungsten carbide and diamond dies. The dies must be flooded with a liquid to cool them and lubricate the fast-moving wire.

The correct emulsion of lubricant and water for a die coolant varies with die size and drawing speed. Too little lubricant causes slivery wire . . . too much causes undersize wire. Therefore, the coolants pumped to the many Belden wire-drawing machines are under the constant observation of a laboratory technician. Fat content tests are frequently made with a Babcock tester to be sure that each wire-drawing machine is supplied with the correct emulsion.

These tests, like the many other Belden process inspection tests, explain why the name "Belden" stands for the highest quality in magnet wire.

Belden Manufacturing Company
4635 W. Van Buren St., Chicago, Ill.

Babcock test bottle showing percentage of fat in die coolant

Belden

BELDENAMEL • SILKENAMEL • COTENAMEL
PAPERENAMEL • FORMVAR • LITZ WIRE
and Other Insulated Round and Rectangular Wires

ELECTRICAL ENGINEERING. Published monthly by the American Institute of Electrical Engineers; publication office 20th & Northampton Streets, Easton, Pa. Editorial and advertising offices, 33 West 39th Street, New York, N. Y. Subscription $12 per year, plus extra postage charge on all countries to which the second-class postage rate does not apply; single copy $1.50. Entered as second-class matter at the Post Office, Easton, Pa., under the Act of Congress of March 3, 1879. Accepted for mailing at special postage rates provided for in Section 538, P.L. & R. Act of February 28, 1925.
January 1943, Vol. 62, No. 1. Number of copies this issue 24,900

KIRK & BLUM

Cubicles

for UTILITIES

Control and Distribution

These cubicles shown on production line (in various stages of construction) are part of a large rush order, delivered on time, for a new war production plant. An outstanding example of Kirk & Blum Service in fabricating sheet metal equipment to meet particular specifications.

Get new installations going without delay. Let Kirk & Blum build your sheet steel Switch Gear Housings, Cubicles, Control Desks, Bus-way, Instrument Panels, etc., while remodeling or expansion is under construction. Have them arrive on the job when needed and installed quickly and easily.

Send us your blue prints for prompt quotations

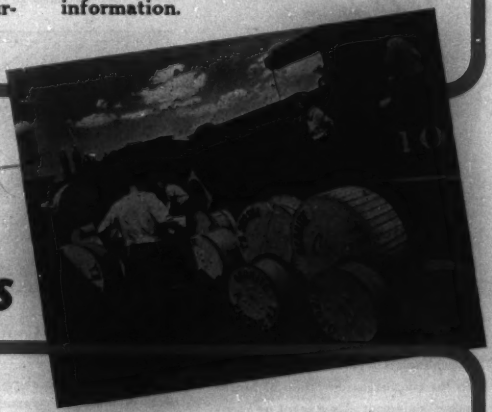
Send for Booklet,
"DATA ON KIRK & BLUM PRODUCTION FACILITIES"

THE KIRK & BLUM MANUFACTURING CO.
AN ORGANIZATION OF ENGINEERS AND MECHANICS
2855 SPRING GROVE AVE. CINCINNATI, OHIO

DO:

- order your wire requirements as far in advance as possible, to allow time to apply for material allocations from the War Production Board. Consult with government engineers to check with their requirements before purchasing cable for a *governmental financed project.*
- avoid complicated splices and fittings. Your Okonite representative can tell you how to simplify installations.
- supply us with cutting lengths promptly as we cannot start manufacture, in most cases, until we have this information.

To Expedite Shipment of Wires and Cables



DON'T:

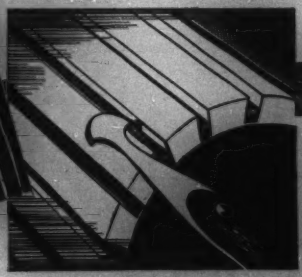
- specify cables that are unnecessarily complicated. Each operation on a cable requires special machines, any one of which may be cause of delay. Keep your cable design simple. Consult your Okonite representative as to how you can do this.
- order short lengths of many sizes. Standardization on a few sizes almost always results in lower cost per foot and much quicker delivery.
- send your order in without specifying End Use, conditions of installation, preference rating, priority authorization, army, navy or other governmental contract number, if any. This information is necessary in order to secure permission to manufacture.

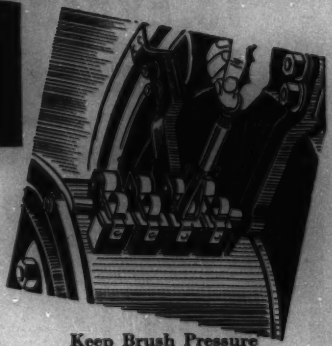
3190

THE OKONITE COMPANY
THE OKONITE-CALLENDER CABLE CO., Incorporated
HAZARD INSULATED WIRE WORKS DIVISION
Executive offices, Passaic, N. J. • Branch offices in principal cities
Salvage Your Scrap — Buy U. S. War Bonds

The A B C of Good Commutation and Electrical Machine Performance

● Serious shutdowns and consequent delays in the production and delivery of urgently needed materials can be avoided by observing these simple precautions in the maintenance of motors, generators and converters. Under present conditions, dependable and uninterrupted performance of electrical power equipment is of utmost importance. Keep your machines in readiness to deliver full output at all times.





a Keep Commutators and Rings Clean

Cleanliness is of paramount importance in the continuous operation of brush-using equipment. Time spent on keeping commutators, rings, brush holders and rigging free from dust, dirt, oil and film pays dividends. Use a suitable canvas wiper frequently on commutators and rings. Keep them clean and keep them running.

b Keep Undercut Commutators Free from Side Mica

Thin edges of mica along the sides of slots of undercut commutators are a frequent source of trouble. Special care should be taken to inspect each slot carefully and to remove all side mica when undercutting commutators. Bad sparking and serious commutator burning can be avoided by observing this precaution.

c Keep Brush Pressure Uniform and Correct

The spring pressure applied to brushes has a marked influence on brush performance. Equal distribution of current among all brushes requires that the pressure on all brushes be kept as nearly equal as possible. Check brush pressure frequently and adjust it to compensate for brush wear. Use pressures recommended for the grade of brush and class of service in which it is used.

MODERN PYRAMIDS will tell you more

This series of bulletins contains practical information on Commutation, Brush Operation and Machine Maintenance to help conserve present equipment and to keep it in continuous and efficient operation. If you are not receiving these bulletins write us direct or contact your National Carbon representative.

The services of our engineering staff are available for the proper selection and application of "National" Carbon Brushes on all types of equipment and for every class of service.

NATIONAL CARBON COMPANY, INCORPORATED

Unit of Union Carbide and Carbon Corporation

GENERAL OFFICES: 30 East 42nd Street, New York, N. Y.

Branch Offices: NEW YORK · PITTSBURGH · CHICAGO · ST. LOUIS · SAN FRANCISCO

62
3

FROM THAT ONE FACT SPRING MANY BENEFITS:

✓ YOU CAN INSTALL THEM INDOORS *SAFELY*: No Pyranol transformer has ever burned or contributed to a fire. Even if heat from a surrounding blaze ruptures the tank, the fire hazard will not be increased.

✓ VAULTLESS INSTALLATIONS ARE POSSIBLE: You can install them indoors or outdoors—in the basement, on the factory floor, on overhead beams, or on the roof. Such flexibility assures you major savings in time, floor space, and construction materials.

✓ PRIMARY POWER CAN BE RIGHT AT THE LOAD: Voltage regulation is improved, line losses are lowered, copper is saved—often up to 30,000 lb in large industrial installations.

AND BECAUSE THEY ARE *LIQUID-FILLED* THEY HAVE:

✓ —A HIGH, *LASTING* DIELECTRIC STRENGTH—an important safeguard against damage from voltage surges caused by lightning and switching

✓ —PRESSURE-TIGHT TANKS, which protect vital parts from dust, dirt, and sabotage

✓ —A HEAT-STORAGE CAPACITY that is ideal for emergency overloads

PYRANOL* transformers fit naturally into your wartime campaigns for (1) safety, (2) stepped-up production, and (3) conservation of critical materials.

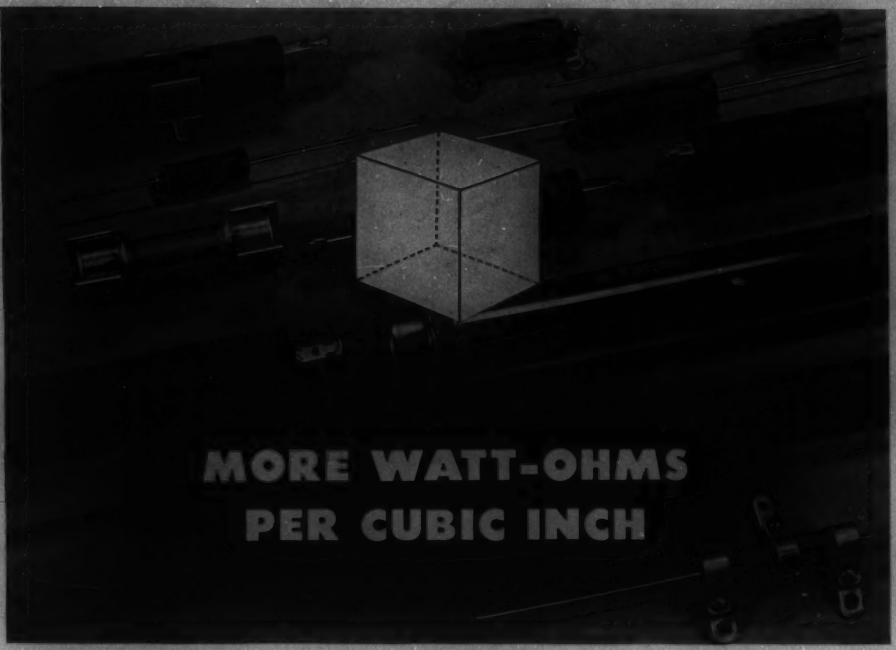
The absence of fire hazard will help you with campaign No. 1. A reliable power supply, easily installed *where you want it*, is an important consideration for No. 2. Fireproof vaults being unnecessary, vital construction materials are saved. Since Pyranol transformers can be located at the load center, the runs of secondary copper are greatly reduced. These are important factors in helping you with point No. 3.

Since the introduction of Pyranol, in 1932, more than 4,000,000 kva of new transformers have been built using this type of cooling and insulating liquid. Hundreds of users are finding that Pyranol transformers assure the lowest total installed cost commensurate with the highest degree of safety.

Ask your G-E representative for the complete story, or write for Bulletin GEA-2048D. *General Electric Company, Schenectady, N. Y.*

*Pyranol is the G-E trade name for askarel.

GE



...greater dependability...easier mounting...less weight

Yes, Mr. Engineer, this is an odd, non-standard technical term—but it is one easily understandable, and certainly one that best explains the tremendous advantages obtained with Koolohm Resistor construction.

...For Koolohms provide the highest wattage ratings and resistance values in a given volume, with safe resistance wire sizes.

...Moreover, Koolohms deliver their full wattage ratings regardless of resistance values.

...Koolohms can be mounted easier and quicker and in less space—directly to the chassis or to grounded parts.

...Koolohms give a big, extra measure of dependability on the high resistance values by using larger wire (2¼ times the cross-sectional area of that used by other manufacturers for these same values).

Koolohms are made with wire that is insulated before it is wound. This insulation is a special ceramic material having a dielectric strength of 350 volts per mil. at 400° C. It is heat-proof to 1000° C, fully moisture-proof, and so flexible it can be wound on small forms, either in short-proof layer-windings, or in high-density progressively-wound interleaved patterns.

Write today for the complete Sprague Koolohm Catalog and sample resistors.

SPRAGUE SPECIALTIES COMPANY
(Resistor Division) North Adams, Mass.

CONVENTIONAL — KOOLOHMS

‹COMPARE!›

Here is an actual comparison between a Sprague Koolohm resistor and a conventional wirewound!

Conventional	Specifications	Koolohm
2.5 mil. minimum	Limiting Wire Size	2.5 mil. minimum
10 watts, 7500 ohms	Rating	10 watts, 7500 ohms
4⅛"	Length	1⅜"
1/16"	Diameter	1/16"
40 grams	Weight	14 grams
Must not come in contact with chassis or grounded parts	Mounting (see above illustration)	Can be mounted flat on chassis or to grounded parts

SPRAGUE
KOOLOHM
WIRE-WOUND RESISTORS

A Wire Wound Resistor Isn't Modern UNLESS It's Wound with CERAMIC INSULATED WIRE!

".do it the *Electronic Way!*"

BETTER . . . FASTER . . MORE ECONOMICALLY

Every day, throughout industry, RCA Tubes in modern Electronic equipment are helping replace both mechanical and human operations on a wide variety of tasks. Every day, they are making possible new standards of accuracy, efficiency, and economy—higher than are practical or feasible by any other method.

So far-reaching has been this industrial development of the Vacuum Tube, it is now the rare industry which does not already utilize various Electronic methods—or, by the same token, stand to benefit by the adoption of many more.

"Do it the Electronic Way" is far more than a slogan. It is a direct challenge to every business that has exacting work to be done still more exactingly.

The Electronic Way has few or no mechanical limitations, is often more economical, and provides freedom from the annoying element of human error!

As the acknowledged leader in the pioneering of Tubes for Radio, it is only natural that RCA should also lead the way in the design of Tubes for industrial uses. A wide variety of types, each with a background of proved dependability, affords a broad engineering selection. Write for Power and Special Tube Folder TT-100, or Phototube Folder PT-20RI to Commercial Engineering Section, RCA Manufacturing Co., Inc., 5th Street, Harrison, N. J.

RCA *Tubes* FOR INDUSTRIAL EFFICIENCY

Low Power • Medium Power • High Power • Cathode Ray • Phototubes
Thyratrons • Voltage Amplifiers • Rectifiers, etc.

Synthite* PX-5

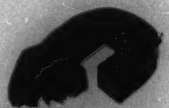
NEW Black Polymerizing Varnish

Not only does SYNTHITE PX-5 Black Baking Varnish cut baking time to a minimum but it also provides better insulation with less coats, thus reducing the number of treating cycles. It possesses excellent flexibility found in the better grades of oxidizing types of varnishes as well as the deep curing properties of synthetic types.

Curing by heat through chemical polymerization, this varnish will dry hard even in the deepest interstices of large coils. Then too, shorter baking will permit flexibility, yet cure the varnish evenly throughout. SYNTHITE PX-5 Black Baking Varnish possesses the essential bonding properties which will hold windings intact under the centrifugal force produced by high speed motors. It is ideally suited for use on the modern types of enamelled magnet wire and Class B insulation.

This material affords maximum resistance to acids and alkalies and can withstand high temperatures. SYNTHITE PX-5 Black Baking Varnish can be applied on all types of electrical units, large or small, and can be baked out by infra-red equipment or the conventional baking oven. In either case, units treated with this varnish will bake out quicker and provide better protection than ordinary insulating varnishes.

- High Dielectric Strength
- Glossy, Tough Film
- Good Adhesion
- Deep Drying
- Waterproof
- Oilproof



The above photograph clearly illustrates the penetrating qualities and thoroughness of curing achieved in using SYNTHITE PX-5 Black Baking Varnish.

* Reg. U. S. Pat. Off.

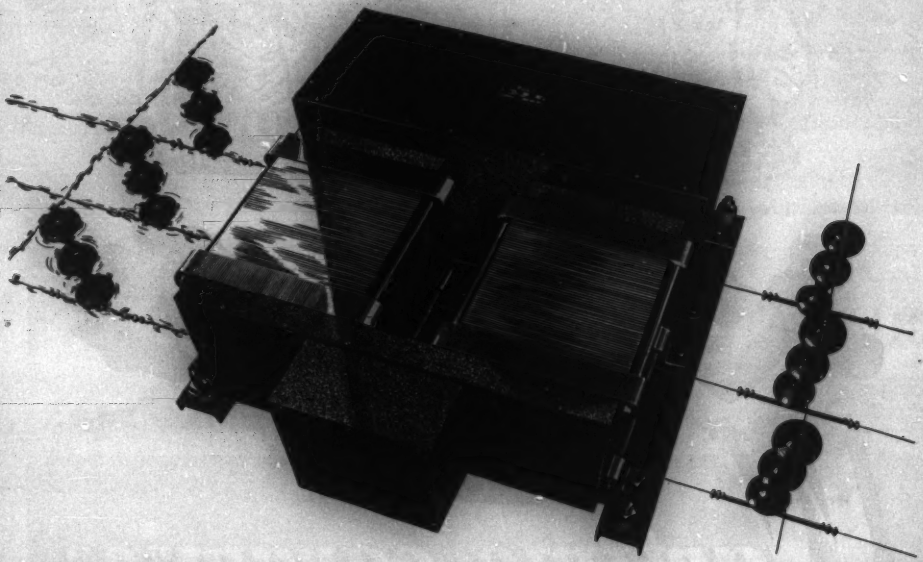
Dolph's

JOHN C. DOLPH COMPANY

Insulating Varnish Specialists

166-8 EMMETT ST. NEWARK N. J.

Industry steadies its "nerves"



FACED with production schedules that have no precedent in history, American industry finds the fluctuating voltages of its over-loaded power lines wholly inadequate to meet the "deadly" precision demanded for total war.

Vital "nerve centers" of production lines are geared for precise performance when operated at specific line voltages. Any variation from these rated values, and there are many these days, may well mean lagging production schedules and a noticeable lack of uniformity in products.

Fluctuating line voltages are no problem in plants where Sola "CV's" have taken over. Even though the peaks and valleys of power consumption may cause a voltage variation of as much as ± 30%—the vital "nerve centers" of their production lines continue to operate smoothly and with unerring precision.

Day and night, without care or supervision, Sola Constant Voltage transformers maintain positive control over electrically operated instruments and machines that are indispensable to the nation's war effort. These transformers are available in standard units with capacities ranging from 15 KVA, which might be used for an entire communications system for instance, to the small 10 VA units for vacuum tubes. Special units can be built to specifications.

Note to Industrial Executives: *The problems solved by Sola "CV" transformers in other plants may have an exact counterpart in yours. Find out. Ask for bulletin ACV-74*

SOLA
Constant Voltage Transformers

Transformers for: Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-ray Equipment • Luminous Tube Signs Oil Burner Ignition • Radio • Power • Controls • Signal Systems • Door Bells and Chimes • etc. **SOLA ELECTRIC CO.,** 2525 Clybourn Ave., Chicago, Ill.

ALSIMAG 1943

Wartime ceramics

Men and guns and ships were about the only materials actively participating in past wars. Spirits were enlivened and conversions swallowed by men and places bearing appropriate monuments. Our commemorative jugs, fashioned by earlier American ceramists, billed purposes the memory of men found in war and peace.

But today ceramics play an active and vital role in war. Complex electrical mechanisms depend upon AlSiMag ceramic insulators for unfailing performance.

It was a proud day for American Lava Corporation when it was the first in the land to produce electrical insulators meeting Navy "Q" specifications. Since that time AlSiMag insulators complying with the toughest specifications of Army and Navy have gone out of this plant in an ever-increasing flow.

The men who make AlSiMag have only one regret. The silent efforts of the past two years have forced them to lose touch, for the time being, with many prominent friends and customers. Every consideration beyond the war effort was possibly and gladly thrust aside. But when peace comes, you will find that the secrets and stamina of war have resulted in new and better AlSiMag products, backed by the same alert organization ready to serve you in the same old spirit of friendly helpfulness.

ARMY E NAVY

AWARDED JULY 27, 1942

AlSiMag

TRADE MARK REGISTERED U. S. PATENT OFFICE

AMERICAN LAVA CORPORATION

CHATTANOOGA, TENNESSEE

BETTER CHECK NO. 2 MOTOR BILL—IT'S RUNNING HOT
OKAY! I'LL TAKE THE AK-1 FOR THAT JOB
THE RIGHT INSTRUMENTS MAKE TROUBLE-SHOOTING A CINCH

Which OF THESE HANDY INSTRUMENTS DO YOU LACK?

Type AK-1 Hook-on Volt-ammeter (A-C) Here's the handiest type of instrument for quick load checks. Forget about cutting conductors or interrupting service. Just hook it around the line, flick the selector switch to AMPERES, and you have your measurement. It measures volts also—connect the voltage leads, snap the switch to VOLTS, and take your reading. Accuracy, ±3 per cent. (Bulletin GEA-2950.)

Type AP-9, Medium-size A-C Portables—and Type DP-9, D-C You'll want this instrument for jobs requiring a high degree of accuracy—it's accurate within ¾ of one per cent. It is very portable—size only 2½ by 6½ by 4¾ inches. Available in a-c ammeters, voltmeters, milliammeters, and wattmeters; and d-c ammeters, voltmeters, milliammeters, microammeters, and millivoltmeters. (Bulletin GEA-1784.)

Type AS-5, Pocket-size A-C Portables—and Type DS-5, D-C This one fits easily in a coat pocket (size, 2 by 3½ by 5½ inches), yet it is accurate within one per cent. Available in a-c ammeters voltmeters, and milliammeters; and d-c ammeters, voltmeters, milliammeters, microammeters, and millivoltmeters. (Bulletin GEA-1784.)

Type CF, Inkless Recorders (Portable) Often, a chart record of load or voltage conditions over a period of time is needed to study the duration of peaks and the time when they occur. The CF line is ideal for this purpose. They're *inkless*—ready to go at a moment's notice—no pen to start, no inkwell to fill, and no ink to spill and blur the record. They weigh only 12 pounds. They are very accurate—a-c voltmeters, within 1½ per cent; ammeters, within 2 per cent. Available in a-c ammeters and voltmeters; and d-c ammeters, voltmeters, milliammeters, microammeters, and millivoltmeters. (Bulletin GEA-3187.)

New Low Chart Speed You can now get a 30-day record on a 30-inch chart—with our new one-inch-per-day chart speed. This simplifies survey analysis. Speeds of 1, 2, and 3 inches per hour can be obtained for applications requiring a higher chart speed.

Type CD, Ink Recorders (Portable and Switchboard Types) These recorders are ideal for those applications where a high degree of accuracy is very important. Either ink type or inkless. They are available in a-c ammeters, voltmeters, wattmeters, power-factor meters, and frequency meters; and in d-c ammeters, voltmeters, milliammeters, millivoltmeters, and wattmeters. (Bulletin GEA-1061.)

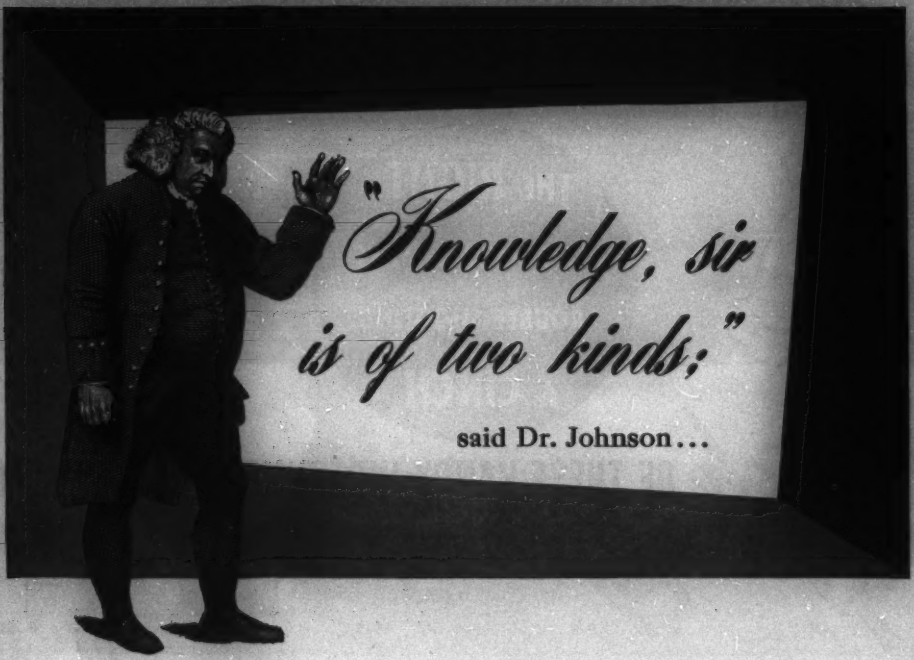
Current-measuring Sets (A-C) Any of the above ammeters can be supplied equipped with a split-core current transformer—the AK-1 has the transformer built in. Thus you can obtain the "hook-on" advantages in these other instruments, too, for load measurements.

These are but a few of the many instruments General Electric can furnish to measure any electrical quantity. If you want information about other instruments, we'll be glad to supply it. Ask the nearest G-E office, or write to General Electric Company, Schenectady, N. Y.

The Army-Navy "E", for Excellence in the manufacture of war equipment, now flies over six G-E plants employing 100,000 men and women.

HEADQUARTERS FOR ELECTRICAL MEASUREMENT

GENERAL ELECTRIC



"We Know a Subject Ourselves or We Know Where We Can Find Information About It"

Wise old Samuel Johnson was not, we suspect, talking about the electronics industries . . . But his statement, like most basic truths, applies directly to the increasing search for knowledge among executives and engineers in this field.

Here at IRC you will find a Service and Information Center staffed by electronic engineers of outstanding ability.

Their work has two main purposes:—to design, perfect and maintain the quality of IRC Resistors; to cooperate with you on Resistor applications of every nature. Their counsel is scientifically sound and scientifically impartial whether they recommend IRC units or some other make.

If there is a Resistor problem puzzling you, you can "find information about it" here.

Preferred for Performance IRC Fixed & Variable Resistors

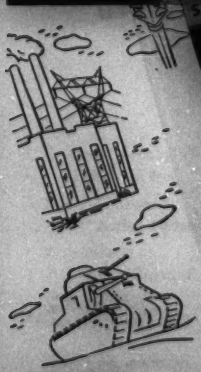
INTERNATIONAL RESISTANCE COMPANY

427 N. BROAD STREET • PHILADELPHIA

WRITE FOR YOUR COPY TODAY!

JUST OUT!

Design, engineering and catalog data on the nation's most complete line of quality relays and timers including many types for war requirements.



THE NEW DUNCO CATALOG AND RELAY-TIMER DATA BOOK

● Far more than a catalog, the new Dunco Relay-Timer Book is a complete guide to relay selection and usage. Fully revised, greatly enlarged, profusely illustrated, replete with detailed specifications and engineering information, and prepared with a particular eye to war equipment requirements, it is a book that should prove helpful to designers, engineers, purchasing agents, production executives and maintenance men alike.

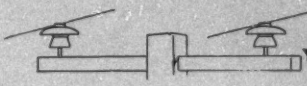
Write for your copy today—or as many copies as may be required to equip your organization. Please mention company connection.

STRUTHERS DUNN, INC., 1321 ARCH STREET, PHILADELPHIA, PA.

YOU USE PORCELAIN INSULATION HERE

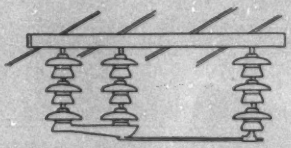
YOU USE

PORCELAIN INSULATION HERE



YOU USE PORCELAIN

INSULATION HERE

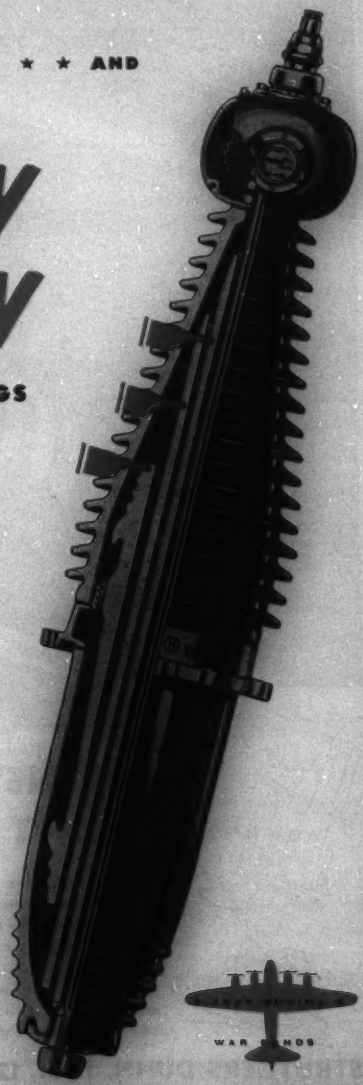


★ ★ ★ AND

PORCELAIN INSULATION

IS ALSO BEST INSIDE YOUR BUSHINGS

Inside a bushing, porcelain dielectric exhibits the same desirable properties it shows out on the line or in a substation ... Porcelain is non-absorbent ... Porcelain is non-carbonizing. Leakage currents cannot set up low-resistance paths, inviting break-down ... Porcelain is un-affected by time. Its superior qualities as an insulator are everlasting ... That's why O-B bushings are packed with porcelain--plenty of it ... That's why O-B bushings are turning in such astonishing service records on the hardest jobs ... That's why you can depend upon porcelain-insulated O-B bushings. We've put a tough insulation where there's a tough job to do. And you get this extra assurance without extra expense. You get it just by specifying O-B.



Ohio Brass

MANSFIELD, OHIO

Canadian Ohio Brass Co., Ltd., Niagara Falls, Ontario

1264-H

ELECTRICAL ENGINEERING

Registered U. S. Patent Office

JANUARY

1943

The Cover: The auditorium of the Engineering Societies Building, New York, N. Y., showing the improved lighting. For details see pages 18–19 of this issue. Photo by F. S. Lincoln

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G. Ross Henninger
Editor (on leave)

Floyd A. Lewis
Acting Editor

F. A. Norris
Business Manager

C. A. Graef
Advertising Manager

VOLUME 62

NUMBER 1

Statements and opinions given in articles and papers appearing in *Electrical Engineering* are the expressions of contributors, for which the Institute assumes no responsibility. ¶ Correspondence is invited on all controversial matters.

Published Monthly by the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Founded 1884

HAROLD S. OSBORNE, President H. H. HENLINE, National Secretary

PUBLICATION COMMITTEE: Howard S. Phelps, *chairman*; C. E. Dean; F. Malcolm Farmer; H. H. Henline; K. B. McEachron; John Mills; A. G. Oehler; P. H. Pumphrey; H. H. Race; S. B. Williams

HIGH LIGHTS . . .

Long-Distance Transmission. An effective way of increasing the permissible straightaway transmission distance is by means of series-capacitor compensation of part of the transmission-line inductive reactance. Results of a study of hunting and self-excitation during normal operation as affected by line and machine characteristics are given. A 300-mile transmission line, terminated at both ends by a transformer of ten per cent reactance is studied by means of an a-c network analyzer (*Transactions pages 41–4*). A comprehensive analysis of representative circuits with and without series-capacitor compensation has been made to determine the regions of abnormal behavior and the effectiveness of various practical methods for safely limiting overvoltages. Such practical means for controlling the overvoltage include proper switching and relaying arrangements, the synchronous condenser, shunt reactors, and resonant shunts (*Transactions pages 32–40*).

Solving Equivalent Circuits. Since it is impractical to analyze the performance of many electromechanical systems by direct calculation, it is important to develop equivalent circuits for these systems that can be solved by the a-c calculating board. Equivalent circuits are set up with the aid of tensorial hunting equations for the determination of the steady-state, hunting, and self-excitation performance of two interconnected instrument-Selsyns, of two salient-pole synchronous machines, and of a capacitor-compensated transmission line connected to a salient-pole synchronous machine (*Transactions pages 25–32*).

Dielectric-Recovery of Air Gaps. The rates at which large air gaps recover dielectric strength after discharging power-frequency currents and short-duration surge currents comparable with those produced by lightning are of fundamental importance in determining power-system performance. Some of the more important considerations are the factors governing the probability of lightning flashovers producing power follow, the probability of power follow producing an outage, and the minimum safe reclosing time after a circuit interruption (*Transactions pages 45–52*).

Ratings for Intermittent Loads. A suggested method for applying motors to load cycles where the motor stops and the ventilation changes in the no-load part of the cycle is based on certain motor-loss ratios, that is, the relation between the losses dissipated with standard temperature rise running and at standstill and the losses at the nominal or short-time rating. This method is said to permit the application of service-factor or short-time ratings to periodic loads with more exactness (*Transactions pages 4–7*).

National Technical Meeting. The national technical meeting of the AIEE to be held in New York, N. Y., January 25–29, 1943, has a scheduled program of approximately 63 technical papers which are to be presented at 13 technical sessions and 12 conferences (*pages 25–6*). Abstracts of 49 technical papers appear in this issue (*pages 27–34*); others were published in the December 1942 issue.

Adjustable-Speed Motor. One type of polyphase adjustable-speed motor and its control circuit provide an a-c drive that has characteristics comparable to those of the Ward-Leonard d-c system. Low costs of this type of motor and its control system, large speed range, facility for rapid reversal by regeneration, and high starting torque make it suitable for many industrial applications (*Transactions pages 7–10*).

Electronic Instrument. An electronic instrument measures the arcing time of a contact closing or opening a circuit by permitting a current of constant value to flow into a capacitor during the time that an arc exists across the contacts under observation; the charge accumulated on the capacitor is therefore a measure of the arcing time (*Transactions pages 14–16*).

Generator Differential Relay. The product-restraint principle, applied to the generator differential relay, permits a variable-slope characteristic without its usually attendant "blind-spot" error. This relay is said to approach the ideal of fast sensitive protection equivalent to that attainable with perfect current transformers (*Transactions pages 11–13*).

System-Grounding Impedance. Causes of system overvoltage are reviewed by a working group on the correlation of system-grounding impedances, of the AIEE committee on protective devices. The correlation of overvoltages with system-grounding impedance is analyzed by means of miniature-system setups (*Transactions pages 17–24*).

Latin American Power Facilities. An engineer who has had technical experience in Latin American countries presents in this issue some interesting data on power engineering in those countries, discussing generating capacity, frequency, hydroelectric power, thermal plants, transmission, and distribution (*pages 3–9*).

Transpositions. Because the fundamentals on which the design of power-line transpositions is based have not always been clearly understood, an engineer of a large midwestern power company has prepared a brief exposition of the purpose and efficacy of transpositions (*pages 17–18*).

Engineering Auditorium Lighting. Those attending the AIEE national technical meeting in New York this month may see the improved lighting in the auditorium of the Engineering Societies Building where many of the sessions will be held, as usual (*front cover; pages 18–19*).

Plastics in Insulation. An authority on plastics, pointing out the increasing popularity of plastics as electrical insulating materials, discusses sources of organic plastics, various forms in which they are available, and electrical properties of plastics (*pages 19–23*).

Patents. The advantages and disadvantages of the existing patent system in the United States are discussed in this issue, with an eye toward using its best elements as a basis for building the most efficient set of patent laws possible (*pages 10–16*).

Capacitor Motors. A method is presented of calculating low-speed performance of two-speed capacitor motors with open-end type of control winding (*Transactions pages 1–3*).

Coming Soon. Among the special articles and technical papers now in preparation for early publication in *Electrical Engineering* are: a discussion of a common error in the distribution factor of electric machines by R. Andriessen (A '40); an article on the electric pasteurizer by John I. Hall (A '39); a discussion of electromagnetic theory by Ernst Weber (F '34), the first of a series on ultrahigh-frequency waves; a report on civilian protection and industrial and utility operations in England during wartime by Davis M. DeBard; a study of formulas for linear conductors of structural shape by Thomas J. Higgins (A '40); an analysis of steady-state and transient stability of long transmission lines with series capacitors by J. W. Bulter (M '38), J. E. Paul (A '39), and T. W. Schroeder (A '37); a description of an electromechanical calculator designed for the rapid solution of directional-antenna patterns by Carl E. Smith (M '38) and Edward L. Gove (M '35); a discussion of emergency loading of transformers by portable capacitor units by Herman B. Wolf (M '37) and G. G. Mattison (A '41); a description of paired-phase arrangement of bus bars for large polyphase currents by Lawrence E. Fisher (M '38) and Robert L. Frank (A '40); an analysis of equivalent ambient temperatures for loading transformers by W. C. Sealey (M '38); discussion of a method of eliminating switching overvoltage hazard in high-voltage oil circuit breakers by Lloyd F. Hunt (F '38), E. W. Boehne (M '37), and H. A. Peterson (M '41), and a description of wood-pole 230-kv transmission lines by O. S. Clark (M '41).

Electrical Engineering: Copyright 1943 by the American Institute of Electrical Engineers; printed in the United States of America; indexed annually by the AIEE, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). Address changes must be received at AIEE headquarters, 33 West 39th Street, New York, N. Y., by the 15th of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge.

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Power Facilities in Central and South America

R. P. CRIPPEN
FELLOW AIEE

Data on generating capacity, frequency, hydroelectric power, thermal plants, transmission, and distribution in the Latin American countries are brought together in this article by an engineer who has had South American experience. Pointing out the likelihood that certain electric equipment used in Latin America will continue to be bought from the United States, he stresses the necessity of reciprocal trade as a means to harmonious relationships within the Western Hemisphere.

DURING World War I the interest of United States industry in South American trade was awakened when European manufacturers were forced practically to abandon exports to South America. Since that time the exchange of exports and imports between North and South America has greatly increased and many factory branches of United States companies have been established in South America.

The present world war has revived the conditions whereby countries to the south are again entirely dependent upon the United States for certain manufactured articles. In turn the United States urgently needs raw products which these countries, together with Canada, can furnish. There is a large degree of self-sufficiency within the hemisphere. The mutual necessities of hemisphere defense are a powerful influence in making North and South America more considerate of each other's points of view and anxious to learn about each other.

The present general interest in Latin America has led to questions being asked about its electrical industry. The data given here in answer to some of these questions are only what are readily available in various published material but it is believed that they will indicate the general conditions. It seems desirable to outline first some simple general facts which influence both the cultural and technical development of the Latin American countries.

Popular writers have dwelt extensively upon the beauty and romance of the Central and South American countries and upon the temperament of their peoples, sometimes with poetic license and often with only superficial knowledge gained in a quick tour. There are many beautiful spots and there is a very romantic appeal in the swaying palms and the Southern Cross and the tango, if one is young and of adventuresome spirit, but in technical and business matters one should pay principal attention to the analysis of facts and figures.

The state of development of these countries and the reactions of their peoples are mainly determined by cir-

Essential substance of an address given at the AIEE summer convention, June 22-26, 1942, Chicago, Ill.

R. P. Crippen is consulting electrical engineer for the International Division of Ebasco Services, Inc., New York, N. Y.

Table I. South America; Population by Area and Countries

Country	Population	Area Square Miles	Persons Per Square Mile	Principal City	Population
Argentina	13,318,320	1,078,278	12.4	Buenos Aires	2,470,000
Bolivia	3,426,296	537,792	6.4	La Paz	250,000
Brazil	41,356,605	3,275,510	12.6	Rio de Janeiro	1,800,000
British Guiana	332,898	89,480	3.7	Georgetown	66,000
Chile	5,000,782	296,717	16.9	Santiago	829,836
Colombia	9,334,392	448,794	20.9	Bogota	330,312
Dutch Guiana	150,000	54,300	2.8	Paramaribo	53,000
Ecuador	3,200,000	275,936	11.6	Guayaquil	140,000
Falkland Islands	2,400	4,600	0.5	Stanley	1,200
French Guiana	37,005	34,740	1.1	St. Laurent do Maroni	1,300
Paraguay	1,000,000	174,854	5.7	Asuncion	107,000
Peru	7,000,000	532,300	13.2	Lima	500,000
Uruguay	2,146,545	72,153	29.8	Montevideo	682,664
Venezuela	3,491,159	352,170	9.9	Caracas	300,000

Total area of South America is 6,800,000 square miles, 13.2 per cent of world's land surface.
Total population of South America is 91,300,000 square miles, 4.2 per cent of world's population.

Total area of continental United States is 2,977,128 square miles.
Total population of United States is 131,669,275 (44 persons per square mile).

cumstances and environment. Under these two headings are included a multitude of influences such as climate, natural resources, geography, history, education, good roads, air travel facilities, and the provincial attitude of superiority of many of the "Norte Americanos" who go south. Latin Americans do very much the same things North Americans do under the same circumstances.

FACTORS INFLUENCING LATIN AMERICAN DEVELOPMENT

It should be remembered that the middle class group in Latin America is a much smaller proportionate part of the population than the large middle-class group in the United States. To a greater extent people in Latin America are either rich or poor. This will be noticed when one goes shopping since one will usually find elaborate and beautiful modern stores which cater to the wealthy and other stores with goods for the low-income groups. But modern department stores with good qualities and moderate prices for middle class people are fewer in percentage than in the United States. There are many excellent schools but they are not available to as large a percentage of the population as those in the United States.

In some of the Latin American countries an appreciable percentage of the population is made up of Indians. Where Indians have had adequate opportunities and educational advantages they have often risen to high places among their countrymen.

There are fewer good roads. Such factors as density of population, higher cost of automobiles (which must be imported), and lower percentage of people with sufficient income to purchase an automobile, all have a bearing on the number of good roads.

Climate, geography, and resources are, of course, fundamental in determining the development of a country but must be considered for each country separately.

Spanish is spoken generally throughout all of Central and South America except Brazil, where Portuguese is used. Very few people stop to realize, however, that this means that half the population of South America speaks Portuguese and not Spanish. There is some similarity between the two languages but not enough to allow anything of consequence to be accomplished by trying to use Spanish in Brazil, or by trying to use Portuguese in Spanish speaking countries. Fortunately educated Latin Americans often speak English.

Table I shows the areas of South American countries, their population, the average density of population, and principal cities and their populations. The total area of South America is nearly 7 million square miles, or 13.2 per cent of the world's land surface and it has a total population of 91 million, or 4.2 per cent of the world's population.

Brazil is the largest country of South America, having approximately half of both the population and the area. It is very rich in natural resources. It is slightly larger in area than the United States, excluding Alaska, and has slightly less than one third the population. The average density of population is, therefore, a little less than one third of that in the United States, which is 44 persons per square mile. This low density of population is characteristic of the larger countries in Central and South America, although Cuba and some of the Central American countries, particularly El Salvador, have a greater average density of population than the United States.

Rio de Janeiro is the capital and principal city of Brazil and has a population of nearly two million. It is justly famed for its beautiful harbor. Sao Paulo is the chief industrial city and has a population of 1,320,000.

Buenos Aires, capital of Argentina, is the eleventh largest city in the world and the largest in Latin America, with a population of nearly 2,500,000. It is modern, cosmopolitan, businesslike, and in some ways more attractive than cities of similar size in the United States. It has a subway system. The next largest Argentine

Table II. Central America, Mexico, and Cuba; Population and Area by Countries

Country	Population	Area Square Miles	Persons Per Square Mile	Principal City	Population
British Honduras	58,759	8,598	6.8	Belize	17,000
Costa Rica	616,000	23,000	26.8	San Jose	65,000
Cuba	4,228,000	44,164	96.0	Havana	568,913
Dominican Republic	1,581,248	19,332	82.0	Trujillo	71,297
Guatemala	3,248,000	45,452	72.0	Guatemala City	170,000
Honduras	1,105,504	44,275	25.6	Tegucigalpa	35,000
Mexico	19,478,791	763,944	25.5	Mexico City	1,754,355
Nicaragua	1,380,287	60,000	23.0	Managua	80,000
Panama	467,459	33,667	13.8	Panama City	85,000
El Salvador	1,744,535	13,176	132.2	San Salvador	102,000

Table III. Approximate Electric Generating Capacity in South America

Country	Total Power		Hydroelectric Power		Predominant Frequency Cycles
	Installed Kilowatts	Annual Production Kilowatt-Hours	Developed Horsepower	Estimated Potential Horsepower	
Argentina	1,136,100 (1937)	2,300,000,000	42,000	5,000,000	50
Bolivia			6,160		50
Brazil	1,186,882 (1940)	30,00,000,000*	1,300,000	20,000,000	50–60
British Guiana					60
Chile	469,132 (1938)	1,500,000,000**		1,400,000 to 4,600,000	50
Colombia	(1938)	212,000,000		4,000,000	60
Dutch Guiana	No current distributed				
Ecuador	16,500 (1938)	51,000,000	10.000	17,000,000	60
French Guiana	No data				
Paraguay	4,375 (1938)	12,000,000	None	Extensive but unstudied	50
Peru	102,176 (1934)	400,000,000 (1938)	80,000 (1934)	4,500,000	60
Uruguay	126,010†	200,000,000 (1936)	34,000 (Rio Negro)		50
Venezuela		400,000,000 (1941)††			50

Note: These figures are based on reports of the United States Department of Commerce, The South American Handbook (1940), the World Almanac, and other scattered information.

* Estimated. Brazil—85 per cent hydro generation.

** Chile—48 per cent hydro generation.

† Uruguay—1936 figure plus 26,000 kw of hydroelectric capacity under construction on Rio Negro.

†† Estimated.

city is Rosario with a population of slightly over 500,000. Santiago, the largest city in Chile, has a population of over 800,000.

Table II shows corresponding statistics for Central America, Mexico, and Cuba.

As one would logically conclude from these considerations, our neighbors to the south have many cities that are large, beautiful, modern, and sanitary, with the upper class citizens well-educated and highly intelligent. But there are also many smaller and less modern cities and towns where the standard of living of a large part of the population is much lower.

GENERATING CAPACITY

In keeping with these conditions one finds large modern power stations and systems supplying the larger cities and many small isolated plants supplying the smaller towns, which are often too far apart to justify interconnection for the small loads involved.

Tables III and IV show the total installed capacity, annual production, installed and potential hydroelectric capacity, and predominant frequency for the various countries in South and Central America and for Mexico and Cuba.

Buenos Aires is a considerable distance from any hydroelectric source and is supplied from steam-electric stations totaling about 600,000 kw. There are several 50,000-kw modern turbogenerators in these stations.

Rio de Janeiro is near good hydroelectric sites, which are common in Brazil. It is served by 254,000 kw of hydroelectric capacity and a 132-kv transmission system, with a 12,000-kw steam plant as stand-by.

Mexico City is served by a 240,000-kw system which is principally hydro but has some back-up steam.

Santiago, Chile, is served from an interconnected system of steam-electric and hydroelectric units totaling 168,000 kw, which also serves Valparaiso and a number of smaller communities. Another 107,000 kw of hydroelectric capacity is under construction by different agencies in four different plants, which will interconnect with this system.

In the smaller communities stations with a total installed capacity of 25 kw and less are quite common and the smallest central generating station found listed in governmental statistics is 2 kw.

FREQUENCY AND LAMP VOLTAGE

Much of the electrical equipment used in South America has been purchased in Europe and as a result the predominating frequency is 50 cycles and the pre-

Table IV. Approximate Electric Generating Capacity in Central America, Mexico, and Cuba

Country	Total Power		Hydroelectric Power		
	Installed Kilowatts	Annual Production Kilowatt-Hours	Developed Horsepower	Estimated Potential Horsepower	Predominant Frequency Cycles
British Honduras	428 (1935)	800,000			
Costa Rica	21,265*		21,300	Plentiful	60
Cuba	134,500**	400,000,000	4,500	30,000	60
Dominican Republic	7,500 (1938)	20,000,000	5,600	15,000	60
Guatemala	12,100		16,500	1,300,000	60
Honduras	7,500 (1936)		6,700		60
Mexico	628,980 (1936)		500,000	Plentiful	60
Nicaragua					60
Panama	16,825†	41,000,000			60
Puerto Rico					60
El Salvador	12,000 (1938)	30,000,000	5,6000	200,000	60

Note: These figures are based on reports of the United States Department of Commerce, The South American Handbook (1940), the World Almanac and other scattered information.

* Costa Rica, includes 5,000 kw hydroelectric project under construction.

** Cuba, includes 3,000 kw steam-electric unit under construction.

† Cia Panamena de Fuerza y Luz only. Includes 4,000 kw of steam-electric capacity under construction. Does not include Canal Zone.

dominating lamp voltage is 220 volts. A great number of small isolated plants deliver 220 volts direct current and there are still many 220-volt d-c areas even in the larger cities. Most countries have some 60-cycle systems and also have some systems with nominal secondary voltages between 110 and 125 volts. Ecuador has the least 50-cycle equipment of any South American country with only 250 kw of 50-cycle generating capacity.

There is so much confusion in regard to frequency and secondary voltage that it is usually necessary to determine system characteristics in the particular city, or part of the city, where equipment is to be used before it can be specified.

In Central America, Mexico, Cuba, and the West Indies 60 cycles and 110–125 volt lighting predominate, but here again there are some notable exceptions such as Mexico City supplied by 240,000 kw of 50-cycle generating capacity and Merida, Mexico, with 220-volt 60-cycle lighting.

Tabulation of the frequency and secondary voltage used in each city can often be obtained from the Electrical Division, Bureau of Foreign and Domestic Commerce, Washington, D. C.

HYDROELECTRIC POWER

Referring to Table III it will be seen that there is a large amount of potential hydroelectric power in several countries and that in Brazil and Peru a large percentage of the total generation is by hydro power. About 60 per cent of the generation in Mexico is by hydro power. About half the generation in Chile is by hydro power, some of the plants being located at mines high in the Andes, where there are special problems of insulation of equipment.

Hydroelectric possibilities in the countries of South America, except Brazil, are closely related to the Andes which rise rapidly from the sea on the west coast. A little north of a line drawn between Mendoza, Argentina, and Santiago, Chile, is Aconcagua, rising 23,380 feet, and highest peak in the Western Hemisphere. From the Andes a majority of the rivers of the continent flow westward a relatively short distance to the Pacific or eastward a considerably greater distance to the Atlantic.

At the southern end of the Andes the western slope of the Andes is wooded and has good ground storage conditions which are favorable to hydroelectric developments. The eastern slope, however, is barren so that there is little ground storage and the rivers on the eastern slope are flashy and often bring huge rocks down during flood season. There are hydro sites with many good characteristics near Mendoza, Argentina, but this condition of flashiness of the streams must be taken into account. In northern Argentina there is better ground storage.

The 26,000-kw Maitenes Plant of Compania Chilena de Electricidad, is in many ways typical of hydroelectric developments in Chile, although it was constructed in 1924. It has a head of 566 feet and has an interesting feature of storing water by off-peak pumping against a 197-foot head.

Figure 1. Dam of South American hydroelectric development showing masonry construction

Water comes to the pumphouse through a canal and then a tunnel. From the pumphouse a canal carries water around a hill to the main penstocks. Also from the pumphouse other smaller penstocks extend up the hill at an angle of about 45 degrees to a storage basin. From the top of the main penstocks a small canal extends on around the hill and brings in additional water from a small drainage area in the canyon on the other side of the hill.

At off-peak periods the two 2,000-kw synchronous machines at the pumphouse are used to drive pumps on one end of their shafts, which pump excess water to the storage basin. During peak-load periods the stored water is drained back down the hill and drives hydraulic turbines on the opposite ends of the shafts from the pumps. The synchronous machines act as generators to reclaim 4,000 kw of power before the water is carried on down the hill to the main generators.

Masonry construction of both powerhouses and dams is often used in South America. The workmen there are expert in this type of construction. Figure 1 shows construction work now in progress on a dam in Chile. Water is to be brought through a hill and after developing 14,000 kw at the plant will be discharged into the forebay of another plant to give this plant more water and an additional 4,000 kw of prime capacity on the present machines.

Along the southern coast of Brazil is a narrow coastal plain often only 10 to 15 miles wide which extends for several hundred miles. At the inner edge of this narrow strip is an abrupt rise of about 2,500 feet, known as the Serra do Mar, at the top of which is the plateau that constitutes the southern part of Brazil. The elevation of this plateau gives it a moderate climate and many of the mineral and agricultural resources of the country are in the area. Sao Paulo is on this plateau and the main industrial development of the country centers around it.

Most of the large amount of potential hydroelectric power of Brazil is in the rivers originating on this plateau.

From the top of the Serra the land falls away gradually to the west. Prevailing southeast winds bring moisture-laden atmosphere in from the South Atlantic. As it rises over the Serra it is cooled a few degrees, resulting in an area of very heavy rainfall just over the edge of the Serra on the plateau. Here rainfall averages 16 feet a year in certain places and sometimes reaches 22½ feet, decreasing further inland to 4 or 5 feet annually.

Many of the rivers originating on this plateau flow westward and unite to form the mighty Parana River which flows southward. At the Argentine–Brazilian border the Parana River is joined by the Iguassu River just after it has passed over the famous Iguassu Falls, which are between Brazil and Argentina. These falls are 200 feet high and the front of the falls is a mile and a half long. They rival Niagara and constitute a potential 250,000-kw development.

About 250 miles downstream from the confluence of the Iguassu River with the Parana are the Rapids of Apipe, between Argentine and Paraguay, with a potentiality of 500,000 kw. After being joined by the Paraguay River and smaller rivers, many of which have originated in the Andes, the Parana and Uruguay Rivers unite just above Buenos Aires to form the Rio de la Plata, which is 29 miles wide as it passes Buenos Aires and which empties into the Atlantic Ocean at Montevideo. Waters which fell as rain a few miles from the Atlantic at the top of the Serra do Mar have traveled nearly 2,000 miles and dropped 2,500 feet to get back to the Atlantic again.

The Serra Development of the Sao Paulo Tramway, Light and Power Company is near Sao Paulo. It is famous because of its potentiality of 1,500,000 kw and also because of the novel method of storing water at the top of the Serra do Mar by a series of interconnected reservoirs. So far the main storage reservoir and one auxiliary storage reservoir have been constructed, as well as a small forebay reservoir for the penstocks down the Serra. Water in the auxiliary storage reservoir is discharged into a river bed which has been cleared out to form a canal. From this canal it is pumped through a head of from 25 to 85 feet into the main reservoir.

The canal also extends on past the auxiliary storage reservoir to a point on the Tiete River. A pumping station is installed at this point so that water from the Tiete River can be pumped through a head of about 15 feet into the canal and then from the other end of the canal into the main reservoir as described.

Water that is pumped through heads of from 25 to 100 feet in the system of reservoirs and waterways mentioned flows down the Serra under a head of about 2,300 feet to the powerhouse on the coastal plain below. At present there are five horizontal units installed with double overhung impulse-type runners. They are capable of carrying a total of 267,000 kw.

Table V. Countries in South and Central America Having Fuel Resources

Coal	Oil
Argentina*	Argentina
Brazil	Bolivia
Chile	Brazil*
Mexico	Colombia
Panama*	Cuba
Peru	Ecuador
Venezuela	Mexico
	Peru
	Venezuela

* Only in small or as yet undeveloped amounts.

THERMAL PLANTS

Table V shows the countries with coal and oil as natural resources. Coal is scarce. Even those countries having coal deposits have not been able to develop them sufficiently to meet all their own needs. As is well known several of the countries have excellent oil resources.

Steam-electric practice does not vary much from that in the United States. The largest units are 50,000 kw and are installed in Buenos Aires, Argentina.

A number of steam turbines built on the Ljungstrom principle are in successful operation but most of these are in sizes of 5,000 kw and less. In these turbines the steam enters at the middle of two rotors which rotate in opposite directions. The steam then flows radially outward through rows of blades that are placed alternately on one rotor and then the other in circular rows. Each rotor drives a separate generator and the two rotors are kept rotating at equal speeds in opposite directions by having the two generators permanently synchronized together electrically.

Diesel engines are used extensively in the smaller stations. In Villa Maria, Argentina, there are two 4,500-horsepower Diesel-electric sets which are believed to be the largest in South America. However, there are not many Diesel-engine sets of more than 1,250 kw installed. Conditions which determine whether a Diesel-electric or a steam-electric set is to be installed vary with kind of fuel most readily available, cost of fuel oil, cooling water conditions, and many other factors. Most of the thermal units of 1,250 kw and above are steam driven. High maintenance costs per kilowatt-hour, as compared to similar sized steam turbines, handicap the larger Diesel sets.

In a few instances where coal and oil are difficult to transport, wood-burning boilers are still in regular operation. Coffee hulls and bagasse are burned regularly in some plants when available and are supplemented by oil or other fuels when the coffee season or sugar cane grinding season has passed.

During the present disturbed world-shipping conditions, several of the countries are having difficulty in obtaining sufficient coal and oil for their needs. In Argentina there is a surplus of corn and bran and these are being burned as fuel.

There are a few remaining engine sets using producer gas made from wood, but these are usually old plants in small towns and are used only for stand-by.

TRANSMISSION

Transmission lines are less common and usually of lower voltages in Central and South America than in the United States. This is because the use of electricity is less per capita, and the towns are often too small and distances between too great to justify interconnections between the present small isolated plants.

The highest voltage lines in South America are the 132-kv lines which bring hydroelectric power to Rio de Janeiro. There are two extensive transmission systems in the state of Sao Paulo, Brazil. An 88-kv transmission system distributes power from the Serra Development of Sao Paulo Tramway, Light and Power Company and a 66-kv transmission system operated by companies associated with the American and Foreign Power Company supplies power to the northern part of the state of Sao Paulo by interconnecting a number of small hydroelectric plants. These two systems can be operated in parallel over the 88-kv lines of the Paulista Railway.

Chile has a 110-kv system supplying hydroelectric and steam-electric power to Santiago and Valparaiso and intervening territory. Argentina has one 66-kv line and some 44-kv and 33-kv lines which will eventually be extended to form parts of more extended interconnections. Venezuela has a 33-kv transmission system bringing hydroelectric power to Caracas. Mexico has several 110-kv and 66-kv transmission systems.

In Cuba there is 416 miles of 33-kv line extending from Havana to Nuevitas and normally operated closed through all the way. This does not include radial branches, but is the shortest transmission distance between the two end points. Most of it is single circuit, only 30 miles being double circuit. At the Havana end there is 90,000 kw of steam-electric capacity and there are a number of steam and Diesel generating stations of up to 5,000-kw capacity and one small hydro station connected to it at various points. Loads are tapped to it wherever they occur. A 4,000-kva synchronous condenser is at present being installed 94 miles from Havana.

Figure 2. "Mensula" construction of distribution lines

Good native poles are scarce in most parts of Central and South America and steel towers are common for transmission construction. However, in some places, such as Cuba and Southern Brazil, hardwood poles are available locally which have good natural resistance to decay or insect attack except for an outer layer of sap wood. Good results are being obtained with such poles without treatment. They are apparently similar to greenheart and wallaba in strength and resistance to decay and insect attack. Some of these latter poles were imported into the United States before the war from British Guiana and are now being tried out on transmission and distribution work.

DISTRIBUTION

A considerable number of systems in South America use 220/380 wye four-wire secondary systems. When the primary distribution system is also four wire, and common neutral construction is used, the resultant distribution system can be quite economical. Where 220-volt lighting is used the secondaries can be extended much farther from the step-down transformers than 115-volt secondary systems in the United States.

Since in many areas good native poles cannot be obtained many of the urban overhead distribution lines are on steel poles. Reinforced-concrete poles are used quite extensively for distribution lines in Brazil and Chile, with varying degrees of success, and they are being tried out in Argentina.

On narrow streets it is quite common to use "mensula" construction, which means brackets attached to the fronts of the buildings or houses. In Latin American countries the houses are usually of masonry construction and built right up to the front property line, which makes the use of brackets practicable. This is illustrated by Figure 2.

On underground systems there is very little use of ducts for the cables. Direct burial is the usual practice. In laying cable, a trench is dug about two and one-half feet deep. Sand is usually poured along the bottom of this trench and the cable laid in this sand. The cable is covered with sand and some sort of protective covering such as boards, bricks, or tile is placed on top of this sand. The fill is then completed and the sidewalk or paving completed over it.

In some places directly buried nonmetallic-sheath cable has proved quite successful, but in other localities and under different conditions difficulties have been experienced with it.

In some instances "kiosks" are used to house distribution transformers. A kiosk is merely a small housing for a transformer which is placed near the curb line and above the surface of the sidewalk. It is like a small vault which is above the sidewalk instead of below it.

RESIDENTIAL, COMMERCIAL, AND INDUSTRIAL LOADS

Table VI shows the average residential consumption for the companies of the American and Foreign Power Company group in various countries in 1939. In general, these averages are low compared with the figure of 1,000 kilowatt-hours being approached as the average for the United States as a whole. This means, of course, that there are more minimum-use customers in these countries than in the United States.

In most of the Latin American countries the supply of servants is adequate and cheap, but they often lack even rudimentary education and are not readily adaptable to new methods of doing things. Cooks often prefer wood- or charcoal-burning stoves or ovens. Electrical appliances often deteriorate rapidly or are actually destroyed by incompetent handling.

Nevertheless electric pressing irons are quite popular. Also washing machines are gaining acceptance in new places because laundresses wear out clothes rather rapidly through old-fashioned scrubbing methods. In a few places such as Guatemala and Colombia electric cooking has gained considerable favor and the average use is high.

For the last ten or fifteen years there has been a steady and substantial rate of growth shown by commercial and small industrial loads in many of the Central and South American countries. This is due to a steadily increasing tendency toward local manufacture of many small articles that are used on a large scale by the local population. The enterprises are small enough so that they can be financed by local capital without too much difficulty. The falling rate of exchange of many of the currencies during the last few years and resultant foreign exchange difficulties have encouraged this tendency.

ELECTRICAL MANUFACTURING PLANTS

Argentina and Brazil have more facilities for the manufacture of electrical equipment and materials than any of the other countries. Each has a cable manufacturing plant where rod copper is drawn down and fabricated into many types of conductors up to 15-kv paper-insulated lead-covered cable. Each has an assembly plant for watt-hour meters. Transformers and insulators are made in Brazil.

It probably can be anticipated that local manufacture will increase in those things which find widespread use in each country. But for a long time to come many of those things which are large, or special, or of which not many are needed, will continue to be purchased from the United States or Europe. There will not be enough demand for large articles requiring highly specialized manufacturing equipment to allow equipment to be obtained and an organization to be set up locally to make them economically.

But if we in the United States are to sell Latin America such equipment we must bear in mind that our trade has to be reciprocal. Latin America cannot buy from the United States if the United States does not buy from Latin America, whether it is Argentine beef and grains, Chilean nitrates and copper, Bolivian tin, or Brazilian coffee.

OPPORTUNITIES FOR ENGINEERING GRADUATES

Questions are often asked about the opportunities for engineering graduates in Central or South America. There is little present need for inexperienced technical graduates of United States citizenship in these countries. Legal restrictions in the form of labor laws or requirements for engineering licenses practically prohibit engineers of United States citizenship from being employed for engineering work in several countries, unless they were already resident in the country when the laws were passed. The countries having such laws usually have universities with good engineering courses and good technically trained men are available from these schools. Occasionally there is need for an engineer with specialized training in some particular type of work.

Table VI. Average Kilowatt-Hour Sales Per Residential Customer in 1939

Ebasco Client Companies in Central and South America

	Kilowatt-Hours Per Year
Argentina	236
Brazil	295
Chile	489
Colombia	479
Cuba	272
Ecuador	318
Guatemala	516
Mexico	275
Panama	397
Venezuela	433
Average	371

Note: Costa Rica not included because most of residential customers are still on flat rate.

There is little occasion to employ inexperienced engineers of United States citizenship in electric-utility work in Latin America, even in those countries where their entry is less difficult. It is sometimes desirable however, to employ engineers of United States citizenship for special or supervisory work.

In spite of the lack of opportunity for employment of inexperienced engineers in these countries it seems desirable to encourage the teaching of Spanish and Portuguese in United States schools because they are live languages for which engineering graduates in the United States may find practical use.

It seems evident that after the war the relations of the United States with its neighbors to the south are going to be closer than ever before. The mutual solution of present problems will lead to increased mutual respect and understanding, which will not be lost when war conditions have passed.

Inventions, Patents, and the Engineer

WILLIAM E. CRAWFORD
FELLOW AIEE

SOMEONE has said, "Marconi, too, had to meet that infallible test of greatness—the threat of some fool to shoot him for having brought to the world a great blessing. We always try to crucify our benefactors."

Some of you are in a real sense the "benefactors." But we must keep in mind that we are all benefited by the many inventions and improvements being made. Let us not crucify those who would bring the blessings to us.

Benefits derived by the engineer and by the public from the United States patent laws are surveyed here by an engineer. He discusses the opposition and the apathy of certain groups toward the American patent system and points out the importance of stimulating the interest of engineers in the attacks upon it. Although he recognizes shortcomings in the system, he urges that those of its elements "that have made the United States outstanding as an inventive nation" be retained as a foundation for a program of improvement.

Many of you are employed to search for new things. Your own bread and butter comes from the fact you are able to produce something no one else has yet produced. For whom? Not for yourself alone, but for all, since knowledge once created and published to the world is of common benefit. But who pays you? Whether you work for a corporation or yourself, almost surely, your actual pay always has to come from some industrial unit. Such a unit constitutes a family composed of stockholders or investors, managers, and workers producing something for the public.

Others of you engineers deal mainly with engineering principles, such as the economical utilization of forces and materials. These are applied to problems of construction. The construction or reconstruction comes, however, mainly because of obsolescence of the old by the appearance of the new. You are also actively employed because of the progress of creative activity.

We should then be interested in invention. But inventions are generally associated with patents, and patents are the subject of much public controversy today. When it comes to patents it probably is true that "fools rush in where angels fear to tread." However, we can't afford to be angels that are frustrated by our fears, nor fools that try to write finis on all the arguments which may exist.

It is important at the outset to agree on the meaning of the term invention. The statutes do not define it and the dictionary meanings are abstract. To me invention simply means something new and useful. It is in this sense that I propose to employ the term. I am aware that in this definition there is a twilight zone, because invention depends on facts. Nevertheless, we need not exhaust our energies in trying to determine the limit of that zone.

When we speak of invention, we think of patents. The terms are not synonymous, but the general public thinks of them in that sense. The Constitution gives the Congress the power to take steps to promote the progress of the arts and sciences. This power is discretionary and early in the history of the United States the patent laws were enacted by Congress to promote and protect inventions. Some people approach the question as a Constitutional one, and feel that the Constitution has guaranteed the "exclusive right for limited periods." To them patents are property and cannot be taken away without due process of law. I think it should be pointed out that the patent laws may be repealed or changed by Congress, or another system enacted.

INVENTIONS AND THE PUBLIC

The engineer enjoys a professional status that involves a responsibility to the community. He has no right to look at inventions from a purely selfish viewpoint. Let us then first inquire how inventions benefit the nation, and next, their immediate effect upon the engineer.

The difficulty of creating new inventions is enhanced by the public's timidity and scepticism toward new inventions. This is true even though the invention is a prime benefit to the public. There is today, and there has been since early times, not only disbelief in the possibility of creating new things, but also the studied opposition to the introduction or use of them after creation. An illustration of disbelief in new things is the classic example of a remark attributed to a former railroad magnate when he dismissed Westinghouse and his new air brake with the statement that he had no time to waste on fools, and that an iron engine cannot be stopped by wind.

Other members of the public have opposed inventions on a different score. The cry is raised that the standard of invention has deteriorated and that all the basic in-

Essential substance of a talk given before a joint meeting of the engineering and technical societies of Milwaukee, Wis., sponsored by the Engineer's Society of Milwaukee, on October 1, 1942, at Marquette University.

William E. Crawford is a consulting engineer with the A. O. Smith Corporation, Milwaukee, Wis.

ventions have been made. Let us look at one of these inventions. Edison made the first successful incandescent light. Edison did not originate the idea of employing the electric-resistance heat of a filament to create light. Yet we are all agreed that this invention is basic. He merely took that filament, which was already known, and made it thinner so that it had a higher temperature and was more incandescent. An engineer of Edison's day or of today would say any freshman should have known what that would do.

In answer to the cry that all basic inventions have been made, I believe we make a mistake in trying to classify inventions into basic and secondary before their history has been made. Edison's light is a good example of a basic invention, which to us appears so obvious that had it not revolutionized the lighting art, we would not today consider it as basic.

From another quarter of the public comes the argument that the multiplication of inventions results in lesser jobs. The answer to this can be found in figures of the National Industrial Conference Board based on the 15th census of the United States quoted from "Men and Machines," a publication of the National Association of Manufacturers. This publication shows that between 1870 and 1937, while the population in the United States increased 218 per cent, those engaged in gainful occupations increased 290 per cent. After the Civil War it required 324 workers per 1,000 of population to produce the goods and services needed, whereas in 1930 it required 398 such workers, because more goods and services were being used.

The national wealth of the United States cannot be increased by obstructing growth, or by ploughing under crops, or by the theory of scarcity. Inventions have promoted commercial progress. The progress of chemistry has given us wallboard from sugar cane, plastics from soya beans, and many new products from corn and cotton, of which the potential benefit to the world is not questioned. This has created new industry and new jobs. It cannot be contended seriously that inventions have not been beneficial to the public.

For example, look at the automobile's pneumatic tire. If improvements are not important and considered as a benefit to the public, we would be back where I paid $35 wholesale for a new casing that wore paper thin in 5,000 miles. It has been estimated that chemical inventions relating to improvement in the manufacture of automobile tires during the years 1928 to 1940 have saved the people of the United States $500,000,000.

It seems clear, therefore, that inventions in the past have been distinctly beneficial to the public and that a little thought and analysis can readily meet the arguments advanced against the promotion of further invention.

INVENTIONS AND THE ENGINEER

How do inventions benefit engineers? The benefit of inventions to engineers is inevitably tied up with the benefit of inventions to the general public. For example, the A. O. Smith Corporation of Milwaukee, Wis., developed some new ideas that brought welded line pipe to the market. This pipe was thinner and larger in diameter than the seamless line pipe then known. The sales of a competitor, a large company producing seamless line pipe on age-old lines, immediately decreased. It set to work to recoup, and as a result, developed seamless pipe of a large diameter and thin wall to meet the competition of the Smith Corporation. Welded pipe and large-diameter seamless pipe were given to the public through these endeavors that arose out of healthy competition.

The public benefited by a better and cheaper pipe that greatly enhanced the profitable use and transportation of gas and oil. The engineers benefited by both companies' improvement because more engineers had to be employed to work on the engineering problems involved in meeting the competition. The engineers employed by these companies also gained in income and in standing, because the business of both companies was increased, which created new opportunities for investment in plants and in other products requiring engineering services.

The traditionally natural or human action is to cling to the old and resist the new. The engineer is not immune from such instinct. During our engineering training we are taught principles and, so far as possible, facts. We are concerned with the known already complete. There is often such a lack of contact with creative imagination in school and in work, that there is danger of developing reactionary conservatism toward inventions.

I once met in Monterey, Mexico, a man from the States named Wilson. He was a practical inventor who condemned our whole school system on the ground that our methods of assertion of authority tended to destroy all native imagination possessed by youth. He went so far as to say that a youth should be rescued from such a system by some aid to individualism and personal effort if he is to have a reasonable chance to remain inquisitive.

C. F. Kettering, vice-president in charge of research, General Motors Corporation, Dayton, Ohio, has said that when the General Motors company takes on college men for its research department, it is preferred that they come during the vacation of their junior year, so they both have a chance to appraise each other before the period of school is finished. He said if they survive the two great shocks they always receive, he can hope that they will be O.K. First, it is always a great shock to find out what apparently simple things the great General Motors laboratories are working on, such as, "What is Friction?" The second great shock is that they can find practically nothing about it in the library. It is natural, therefore, that we as engineers should carry over into our work from our school days a lack of inquisitiveness.

A certain man has written a book on "Rules for Suc-

cess." One of his rules, number 816, states, "When confronted with a new idea, you are more certain of being right if you vote against it."

Reasons:

1. It may not be a good idea; it seldom is.

2. Even if it is a good idea, the chances are that it will never be put to a test.

3. Even if it is a good idea, and is tried out, the chances are it won't work the first time.

4. Even if it is a good idea, is tried, and is successful, there will be plenty of time to think up alibis.

Therefore:

"When confronted with a new idea, you are far more certain of being right (or at least safe) if you take a very definite and positive stand against it."

Too many of us, I am afraid, live by this rule. Now most of us know that research is the industrial unit's method of bringing forth new improvements, new inventions. As Justice Felix Frankfurter of the United States Supreme Court puts it, "Research is the systematic indulgence of curiosity." This most of us know. However, the great majority of engineers are not employed on research, but on ordinary engineering problems.

What these engineers do not stop to think about is that it is this very research that creates new engineering problems to work on. New construction and the obsolescence of devices and methods magnify these problems. I say we fail to recognize this fact because we are guided too much by that which is past history. We are too satisfied to cling to the old. We must wake up to the fact that contributions to invention are being made for our benefit as well as that of the general public. We must keep ourselves "in-the-know."

Another point we forget is that it takes other engineers to put into practical application the new improvements found by researches. These other engineers in solving the engineering problems involved in putting into practical operation the improvements created by the research engineer, themselves discover new methods of operation and devices that also become inventions.

Doctor Kettering of the General Motors Corporation has stated that we all keep insisting on looking to the past to discover the future, so much, that, "If we drove our automobiles the way we go forward with technical progress, we would put our steering wheel at the rear of the car so we could look out at the road behind to guide us on the road ahead." This comment applies generally to engineers.

The engineering profession must recognize that the new is beneficial to all, and that engineering jobs are primarily dependent upon new developments arising out of inventions. Further it must be recognized that continued adequate financial support for investment by industrial units is needed to pay for such research and to pay for engineering services. Where engineers make themselves a part of a large industrial unit that is involved in new developments, they must help that unit to get paid for their work and for the investments it has made in newly developed products.

THE ROLE OF PATENTS IN INVENTION

Would anyone while working on a research problem, go to his company's competitor and disclose discoveries so that such company could benefit along with his own, without payment for services rendered by him? The answer is obviously that he would not. It is clearly inconsistent for a company to have to turn over free to its competitor the fruits of the discoveries or inventions of its engineers without a period in which to use the results exclusively to compensate for the money invested in the services of its engineers, and the accompanying expense of tools and materials used in the work.

An industrial unit which has the moral courage to hurdle the opposition expressed in rule number 816 should not at the end of the road find the opposition in a position to take away the opportunity for repayment of the investment made.

And how are the investments of a company in its research departments and in the services of its engineers to be protected? That is where the patent system steps into the picture. There can be no argument but that in the past these investments have been protected by the American patent system, and the patents issued thereunder. It is true that industrial organizations do not maintain research for the purpose of obtaining patents. They do it for commercial reasons only. But they could not afford the cost of research for commercial reasons, if they were not protected in their investments.

PROPOSED CHANGES IN THE AMERICAN PATENT SYSTEM

Dive-bomber attacks recently have been waged against the United States patent system. The "ack-ack" that has gone up to meet such attacks so far, has been feeble, but it appears to be increasing in intensity daily. To view intelligently the battleground, it will be necessary to refer to several groups of information and discuss their interrelation.

First, I am convinced that there are changes that can be made in our patent system to improve the technique of operating it and to eliminate the present confusion in the public mind. These changes should be made and this can be done without injury to the national welfare. It would be gross error to contend that the system is perfect. If that position is taken, we would be guilty of applying rule number 816.

However, Judge Jerome Frank, formerly head of the Securities Exchange Commission, and presently a judge of the Second Circuit Court of Appeals, strikes a note on the changing of the patent system that is worthy of attention. In a concurring opinion in Picard versus the United Aircraft Corporation decided in May 1942,

Judge Frank points out that a statutory revision of the United States patent system should not be too drastic. "We should not throw out the baby with the bath water."

Judge Frank bases his reasons for retaining the patent system not as bait for inventors, but as a lure to investors. He points out that it has sometimes been said that there is no need to coax investors thus, because great corporations with their research laboratories will without such bait do the needful. He says the answer is that industrial history discloses that those corporations, at times and to some extent, have been prodded into undertaking such research and into developing improvements because of the threat of competition from occasional outsiders armed with patent monopolies and supplied with funds by a few private enterprisers.

The attacks on the patent system and the defense thereof have principally occurred before the Temporary National Economic Committee and the Senate patent committee. The TNEC was established by Congress in June of 1938 at the request of President Roosevelt to study the concentration of economic power and its injurious effects upon the American system of free enterprise.

Publicity on the aspects of the TNEC hearings affecting patents has been given impetus by the National Association of Manufacturers. Under their auspices George E. Folk has recently published a booklet entitled, "Patents and Industrial Progress." It merits the attention of those who are interested in gaining further knowledge of the TNEC hearings. The NAM has been very active in reviewing and publicizing all angles concerning patents. Edwin B. H. Tower, Jr., president of the Milwaukee Patent Law Association, has done a fine job in keeping in contact with their work. He has also been active in promoting interest in Milwaukee on patent problems and in making suggestions to the NAM and to other interested groups.

I personally attended some of the hearings of the TNEC upon one of my trips to Washington. Some of the most significant statements that I heard were made by Edsel Ford and his attorney, J. I. Farley. Ford and Farley testified that they did not ask royalty for patents that they hold, and that their company could proceed without patents. Mr. Farley, however, emphatically stated that patents were necessary to perpetuate the small manufacturer and to aid the individual inventor. He made the further point that if the small manufacturer had no protection of his investment in his improvement by temporary exclusive use, such manufacturer would not be able to obtain capital to launch his enterprise.

The automobile industry has often been held up as the example of one industry which has more or less eliminated the effect of patents by employing a free cross-licensing system among the members of that industry.

However, it is interesting to note that the original most important automotive advances occurred before the establishment of the cross-licensing system in 1915. In each of the new five-year agreements in 1930 and 1935 entered into by the automobile companies, new patents were not added to the agreement. The reason for this was that the separate companies were expending considerable sums of money in research the results of which they could not afford to contribute by license without a commensurate return.

The Packard Motor Car Company never entered into these agreements. I was present at the TNEC when Milton Tibbetts, of that company, testified. The reason the Packard company did not enter into these agreements, as I recall, was because of their active research program, which they could not afford to contribute. It is a self-evident fact that no company or group can continue to play Santa Claus to competitors who are trying to put them out of business by lowering the price to the point at which no money is left for research.

Before the TNEC, the Justice Department continually maintained that industry has used patents to suppress invention. This type of accusation has appeared again at the recent hearings of the Senate patent committee.

Vanevar Bush, president of Carnegie Institution, Washington, D. C., testified before the TNEC that suppression of patents did not present a serious problem. According to Doctor Bush, never in his experience had he seen a beneficial invention held away from the public. Other qualified individuals supported Doctor Bush in similar statements before the TNEC. The testimony before the TNEC and the more recent hearings of the Senate patent committee failed to disclose any single case of the employment of patents to suppress an invention.

With reference to the recent hearings of the Senate patent committee, testimony on bills introduced into the Senate by Senators Bone and LaFollette on the subject of commandeering patents during the war was originally scheduled to be heard. The hearings, however, were expanded to give publicity in co-operation with the Justice Department to international cartel agreements. In these hearings, the public has been repeatedly presented with alleged abuses in big business, and no effort has been spared to lay such claimed abuses at the feet of the United States patent system.

Confusion on the issues involved has been enhanced by dragging the antitrust laws into the picture. Great fundamental differences exist between the monopolies in restraint of trade prohibited by the antitrust laws and the limited exclusive rights of a patentee under a patent. No distinction has ever been made by the Justice Department. The patent laws and the antitrust laws are founded on sound policy. They both operate to the benefit of the public, but there is a line between them that cannot be defined by geometric definition.

To date, I believe that almost no testimony has been taken directly on the advisability of the bills originally up for consideration before the Senate committee. The testimony that has been taken on international cartels

has shown that instead of United States patents on foreign inventions being used to prevent manufacture in this country, they have, in fact, had the opposite effect.

I had the opportunity to listen to testimony in the Plexiglas case. Many questions were aimed at trying to show that Rohm and Haas of Philadelphia, Pa., had made agreements with German companies which, in the words of the publicity concerning these Senate hearings, constituted "holding hands with Hitler." To me the answers were straightforward and convincing. Rohm and Haas testified that if it had not been for these agreements and the technical information obtained from the German concern, the United States would have been buying its nonbreakable plastic glass for the front-end housings of airplanes from Germany, at the time of the declaration of war on us by Germany. They offered to show that the cost to the Government was close to the cost of production. This information was refused on the basis of military secrets. They then were attacked for the alleged charge of $15 a pound for similar material to make false teeth. After it was shown that only a small fraction of this price got to Rohm and Haas and that most of it was dental industry margins, the questioners still persisted in reading into the record statements about $15 a pound.

Thus it is that in connection with Plexiglas, Carboloy, synthetic rubber, and other products, it has been demonstrated before the Senate patent committee that it was the existence of United States patents on these products that has given the United States companies the basis for obtaining the know-how of manufacture from foreign concerns.

COMPULSORY LICENSING OF PATENTS

The guns of the Justice Department before the Senate patents committee have been directed at big business. The attack in one quarter has been directed toward the enactment of a law under which patents could be licensed by legal compulsion. The theory advanced is that compulsory licensing of patents is necessary as a whip to progress.

This is falacious argument. Absence of an exclusive privilege will prevent the private inventor, or more important, the industrial unit, from obtaining or putting up the speculative capital necessary to finance the long development period of a new invention. Furthermore, those interests with strong financial backing would be enabled by a compulsory licensing law to secure privileges from small inventors or small businesses whose sole economic protection lies in the ability to develop new and exclusive products or processes.

At the TNEC hearings, Mr. Tibbetts, patent counsel for the Packard Motor Car Company was asked by Representative Summers, "Is there a good reason why, upon the payment of a proper compensation, anybody ought not to be privileged to use in his business a novel invention?"

He replied, "The best answer I would have to that is that with small companies, particularly where they rely entirely upon their patents and their exclusive use for the development of that company, if they had to license someone else, they would be out of business; that's all."

A compulsory license in effect destroys investment and does not act as a whip to progress. A company could not stay in business if it received only enough to pay for the expense of its successful inventions. The reason being that other extensive research is necessary to obtain such inventions. It is well known that for every successful research project there are numerous unsuccessful projects. Such expense is not taken into consideration under a compulsory-licensing law and it cannot be evaluated.

I know of a company that was held to infringe a valid patent on a stovepipe joint. Before the case was completed, the engineers of the infringing company brought out a completely new and noninfringing joint that was superior to that of the winning company, and good enough to capture a large proportion of the market sales. In this way, the public is benefited by the progress that was compelled by patents. Such a benefit could not result from a system of compulsory licenses in which competitors could make the same products. The present patent system in the United States acts as a whip to progress by giving protection for a limited term of years to the inventions the other fellow has made.

I know that many times the engineer is tempted to say a patent is nothing but a headache. It stops him from indiscriminately using things, the principles of which he thoroughly understands. He questions whether the patent of the moment expresses invention; for he is often convinced that if his logical mind can comprehend it, certainly it took no invention to create it. He does not stop to ask in borderline cases how well it would be to put that idea back into the mind of the originator and bury them together, and what a loss to the public would result.

In the case where a patent unexpectedly looms up in front of the engineer, he may nearly have heart failure, but he has to jump from that rear steering wheel to one in the front of the car and for a while at least, actually look where he is going. He learns something he seldom learns in school, and that is, to appraise so thoroughly all the angles of the thing in which he is engaged, that he becomes able to create something that not only is as good or better than the patent, but probably new. The patent has whipped him into efforts that produce something for the progress of mankind.

FOREIGN APPRAISAL OF U. S. PATENT SYSTEM

A look at the opinions of other nations respecting the patent system in the United States helps our perspective.

A certain Swiss manufacturer was invited to the Centennial Exposition in Philadelphia, Pa., in 1876. At that time, Switzerland, while a comparatively industrial nation, did not possess a developed patent system. This

Swiss manufacturer, upon his return to his own country, made an address in praise of our patent system and advocated its emulation by the Swiss Government, making reference in his speech to the importance of the American patent system as an aid to industrial progress. In his address, he said:

"I am satisfied from my knowledge that no people has made, in so short a time, so many useful inventions as the American, and if today machinery apparently does all the work, it nevertheless, by no means, reduces the workman to a machine. He uses it as a machine, it is true, but he is always thinking about some improvement to introduce into it; and often his thoughts lead to fine inventions or useful improvements."

Subsequently, the Swiss patent system was established in 1888.

It is worth noting also that Japan looked on the American patent system as a big factor in the greatness of the United States. Prior to 1899, the date Japan established her patent system, a special Japanese official was in the United States to investigate the American patent system. Doctor P. B. Pierce of the United States Patent Office asked this man why Japan wanted a patent system. His reply was:

"I will tell you. You know it is only since Commodore Perry, in 1854, opened the ports of Japan to foreign commerce that the Japanese have been trying to become a great nation, like other nations of the earth, and we have looked about us to see what nations are the greatest, so that we could be like them, and we said, 'There is the United States, not much more than a hundred years old, and America was not discovered by Columbus 400 years ago. What is it that makes the United States such a great nation?' And we investigated and we found it was patents, and we will have patents."

ATTITUDE OF COURTS TOWARD PATENTS

There has been considerable publicity to the effect that the courts are against patents. It must be remembered that in a patent case the court is generally confronted with the bare fact—is there invention? There are no precedents that can positively be relied upon by the court. The statutes do not define invention. The courts are naturally conservative and they view the device from afar, in that a patent case cannot possibly present to them all the background and behind-the-scenes knowledge that surrounds the development of the particular patent.

It is easy for all of us to exercise a better hindsight than foresight. The courts thus often hold that there is no invention because the device to them seems simple and readily made by anyone with ordinary mechanical skill. An engineer, no doubt, on many occasions, has experienced this same sort of feeling in studying an invention developed by another.

I think statistics will bear me out that the courts are no more hostile to inventions and proper patents protecting them, than they are toward workmen's compensation or other cases involving a decision on the facts.

The Supreme Court of the United States which has been accused of taking a decided stand against patents, in the Williams Manufacturing Company versus the United Shoe Machinery Corporation case this past spring, sustained claims of a patent owned by the United Shoe Machinery Corporation and held the same infringed. This indicates in my opinion that the courts are still open minded about patents and the inventions they protect. For the courts to take a prejudiced position would be against the public interests.

At a recent meeting of the American Bar Association, recommendations were officially made by the association directed toward the improvement of the patent system. Whether these are ever actually enacted into law is immaterial. It demonstrates a healthy trend on the part of the association and the patent bar to co-operate in the national movement for the betterment of the patent system.

PATENTS PLANNING COMMISSION

The National Patents Planning Commission was created by President Roosevelt by executive order on December 12, 1941. The order reads in part as follows:

"The Commission is authorized, in conjunction with the Department of Commerce, to conduct a comprehensive survey and study of the American patent system, and consider whether the system now provides the maximum service in stimulating the inventive genius of our people in evolving inventions and in furthering their prompt utilization for the public good; whether our patent system should perform a more active function in inventive development; whether there are obstructions in our existing system of patent laws, and, if so, how they can be eliminated; to what extent the Government should go in stimulating inventive effort in normal times; and what methods and plans might be developed to promote inventions and discoveries which will increase commerce, provide employment, and fully utilize expanded defense industrial facilities during normal times."

In announcing the appointments of Doctor C. F. Kettering, Owen D. Young, Chester C. Davis, Edward F. McGrady, and Francis P. Gaines to the Planning Commission, the secretary of commerce said in part:

"The Patent Planning Commission can, in my opinion, perform a really useful service in postwar planning . . . . For more than a century American industrial development has been encouraged, inventions have been stimulated, and both industry and our people have benefited by the protection which our patent system has afforded American genius. There is reason to believe that a survey of existing facilities and procedure, a study of future needs and the challenge to American inventive effort, undertaken by the Commission in conjunction with the Patent Office, may produce even greater results."

The Patents Planning Commission is composed of competent members. Whether the Commission will function to promote the economic and technical well-being of the country or sink into ineffective mediocrity, will depend largely on the prevailing atmosphere of public interest and opinion in its work.

Headlines have announced the presentations of the Department of Justice before the Senate committee on patents, but the day-by-day achievements of the Justice

Department in proposing helpful changes to the patent system and the steps to take to promote invention are unchronicled because there are none. The friction between the Justice Department and business, the department's taste for scandal, and its preoccupation with personalities, make us realize that the department can only act as a springboard to encourage action by others better qualified to act.

The public is surprisingly uninformed of the extent to which the patent system has contributed to the public good and the activities of the Justice Department do not present the patent system in the proper light. The podium of the Patents Planning Commission is the stage upon which the true facts can be brought to the public.

Engineers can help the Patents Planning Commission and the general public by working through their respective technical and professional organizations and their committees to convey to the commission interest in the investigations and findings of the commission, with respect to inventions and patents. Engineers should hold themselves ready to give assistance when called upon so to do, and to present helpful suggestions through their committees, if such action seems appropriate.

All are agreed that the country needs not less but more of that which has enabled it to outstrip other nations industrially. The National Patents Planning Commission may find ways of making the patent laws even more effective in the future economy of the United States.

CONCLUSION

We believe in competition, in the excitement of conflict, and the testing of man against man in a fair fight. In the economic system of the United States, the dynamo is self-interest—a self-interest which may range from mere petty greed to admirable types of self-expression.

The patent system protects the powerful drive of self-interest and in doing so promotes the general welfare. For most of us as engineers self-interest is centered in more income and greater recognition and standing in our industrial unit and our profession. The patent system makes it possible for this self-interest to be nurtured by protecting industrial units in their investments in us. Without such protection as the patent system offers, it would be a wary penny indeed that would find its way into the very things upon which our livelihood depends. Patent protection for a company is protection for their engineers because it enables the company to finance the engineers' work.

What we produce in trying to circumvent competitors' products not only helps our standing in the industrial unit where we are employed and establishes our income, but it promotes the general welfare of everybody as well, because we have produced something new. We have added to that body of knowledge which helps all of us to better enjoy the world we live in. The patent system forces the engineer to produce these new things. Greater progress is made this way than would be possible if one competitor could take over another competitor's product.

The patent grant is in line with the American system under which remuneration is given for accomplishments. Without individual remuneration in some fair proportion to accomplishment, it cannot be hoped that we as a nation will progress in the future.

We, as engineers, must maintain an open mind and liberal view toward the methods employed to continue and to encourage invention. The patent system has proved eminently successful in the past in promoting invention, and in giving us the protection we need in seeking our livelihoods. Let us, therefore, not throw away the staff that enabled us to reach the top of the hill; instead, let's build our house around it.

Mr. Kettering at a recent meeting of the American Bar Association in Detroit told the following story. At one time as a manager of a plant, he put on a campaign to reduce the amount of scrap produced. The departments were caused to bring all the actual scrap into the yard and pile it in a heap. This pile grew until it was very impressive, and great attention was directed to the problem of scrap. The organization, in fact, didn't do much else and a board of department executives met almost daily on the subject.

Finally a smart foreman took a photograph of the immense scrap pile which had been accumulating over a period of six months. He then enlarged this photograph to the proportionate size of the metal going into the finished products and placed the photograph and its enlargement side by side on the wall of the meeting room. He proceeded to point out in open meeting how they had been devoting their time to only $^1/_8$ of one per cent of the total volume of steel used by the company and that the $99^1/_8$ per cent fine products being produced were more important and deserved greater attention. He further pointed out that they should not set their sight so exclusively on the incorrect that they be blinded to the beneficial utilization of the whole.

And so it is that some groups in our nation have directed the attention of engineers and that of the general public to the scrap pile of the patent system. They have dramatized and glossed that scrap pile to such an extent that we can only see bad features in the system. They have made us forget the good in the patent system that far outweighs the bad. They have made us forget that the inventive advances of this country are predicated on patents. And worse, they have made us forget that our very jobs as engineers rest upon a patent system that protects either our own or our company's investments in our work.

We have been lulled into inactivity too long by indifference, by lack of knowledge and misinformation. Let us now, while we are still masters of our fate, lift our eyes from the scrap pile that has been placed before us and look upward to build around and to improve the laws that have made the United States outstanding as an inventive nation, namely, the American patent system.

Power-Line Transposition Practices

F. VON VOIGTLANDER
MEMBER AIEE

This brief exposition of the purpose and efficacy of transpositions in power lines, originally prepared for the engineers of a large midwestern power system, should be of interest to other power-system engineers and communication engineers as well.

POWER-LINE transpositions often have been regarded as nothing less than chicanery and electrical sleight of hand, chiefly because the fundamentals on which their design is based have not always been clearly understood. Transpositions are installed in power lines in which all conductors normally operate at substantially equal potential between phases and to ground, and carry current of equal magnitude and symmetrical phase displacement, for the following reasons:

1. To balance the capacitance of three-phase conductors with respect to ground so as to minimize the characteristic residual voltage of the system.

2. To balance the three-phase conductors with respect to exposed communication conductors, that is, to co-ordinate communication-circuit exposures in which excessive longitudinal induction due to balanced components might otherwise be experienced.

The function of transpositions is essentially to change the phase of induction between two systems of conductors in a mutual electric field, or to balance a system of conductors so as to equalize their capacitances to earth. Transpositions are necessary because of the impracticability of achieving geometrical, and hence electrical, symmetry in commercial open-wire-line systems.

In the past, power lines often were transposed only at the request of communication companies, often without justification, and sometimes in lieu of proper transpositions in signaling circuits. When such signaling circuits subsequently were properly transposed, the influence of power-circuit transpositions frequently was then found to be negligible, tending to the conclusion that power-circuit transpositions were of little value. However, where signal conductors are subject to excessive longitudinal induction, and are otherwise well designed and maintained, power transpositions may be an aid to co-ordination. Each case should be analyzed on its own merits and transpositions should be installed only where they are unquestionably justified. Care should then be exercised in the design; they should not be placed at unreasonably short intervals, as an excessive number of transpositions adds little to their effectiveness, and the simple condition of crossing phase conductors creates potential service hazards and maintenance complications.

BALANCING A POWER SYSTEM TO GROUND

The importance of a good balance to ground on high-voltage transmission systems has frequently been underestimated, with the result that many lines have been indiscriminately transposed or not transposed at all. On systems having grounded neutrals, whether direct grounded or impedance grounded, the normal residual current circulating through the system can be minimized by maintaining a good balance to ground. Since residual circulating current is of no benefit to the power system, proper balancing of the lines to ground so as to limit such current to a reasonable minimum is desirable, as it will mitigate a common cause of inductive disturbances. Modern design of transposition structures eliminates to a large extent the difficulties formerly encountered due to short circuits caused by ice loading and unloading, and to flashovers permitted by inadequate structural clearances.

In systems of such magnitude that electrical resonance or near resonance is encountered at critical frequencies, transpositions will help in limiting residual voltages of these critical frequencies; this will limit the residual current circulating in the system. With systems grounded through resonant neutral-grounding reactors, transpositions may be necessary to prevent current circulating continually through these devices in excess of their thermal ability.

In order that a power system may maintain a reasonably good balance to ground, it is believed desirable that each line section by itself be transposed to give as good a balance as feasible, though it is necessary to consider the entire metallically connected system as a whole to determine the system ground balance. For power lines operating at 60 cycles, transposition "barrels" about 50 miles in length should prove satisfactory where no specific co-ordination is required. The length of the power line or the extent of the power system in general would not influence the length of barrels required, but in some cases extensive systems might require extra transpositions to mitigate the effects of cumulative unbalances due to variations in configuration, and other factors. It should be borne in mind that transpositions can be effected by merely rearranging the phase order of the lines at switching stations and may not require actual "rolling" of the line conductors.

Transpositions become more important with higher operating voltages because the residual currents then usually become greater. Since the higher voltage sys-

F. Von Voigtlander is employed in the electrical engineering department, The Commonwealth and Southern Corporation, Jackson, Mich.

tems are usually of greater geographical extent, the influence of their residuals may become correspondingly quite widespread.

CO-ORDINATION WITH SPECIFIC COMMUNICATION EXPOSURES

Both telephone and telegraph circuit exposures may be benefited by power-line transpositions. However, the co-ordination requirements of these two types of communication facilities may be quite different. For the purposes of this discussion, only the common type of telephone and telegraph systems will be considered, that is, metallic voice-frequency telephone circuits, and ground-return d-c telegraph circuits.

Telephone-Circuit Co-ordination. Power-line transpositions are generally of little value in telephone-circuit noise co-ordination. They should be considered only where excessive longitudinal induction at voice frequencies from balanced components is being, or may be, experienced. Because of the frequency-response characteristics of the human ear and ordinary telephone equipment, noise induction at fundamental frequencies is of no importance; but the harmonics, especially the triples, are of great consequence, particularly in the range from 180 to 2,200 cycles.

The effects of ordinary power induction on telephone-circuit noise can usually be mitigated effectively by proper telephone-line transpositions and maintenance of both power- and telephone-circuit electrical balance. However, in cases of excessive longitudinal induction, noise may be caused by reason of unbalanced impedances in the telephone circuit, even though they are balanced to the best commercially practicable limits. In these special cases, power-line transpositions specifically designed to co-ordinate with a proper telephone-transposition layout can offer some relief. Such power-line transpositions must also be co-ordinated with any others installed for the purpose of balancing the power line, as the indiscriminate addition of transpositions may adversely affect an existing balance to ground, thereby causing an increase in residual current which could result in more harm than good.

Telegraph-Circuit Co-ordination. The use of ground return precludes the effective use of communication-circuit transpositions for the inductive co-ordination of d-c telegraph circuits. As the rate at which the current flow is interrupted in commercial telegraph circuits corresponds roughly to 25 to 60 cycles per second, these circuits are quite vulnerable to induction at fundamental power-system frequencies. Furthermore, the use of ground return causes the longitudinal induction to flow through the same path as the signal current, resulting in false and garbled signals. Power-line transpositions are therefore quite effective in telegraph co-ordination in limiting longitudinal induction from balanced components and in balancing the power system to ground to limit normal residual induction. Such transpositions must be co-ordinated with the power-system transposition scheme and sometimes with telephone circuits carried on the telegraph lead. Ordinarily, transposition barrels less than three miles in length should never be required, and generally they can be much longer.

Engineering Auditorium Lighting Improved

S. W. BRUUN
ASSOCIATE AIEE

THE illumination of the auditorium in the Engineering Societies Building has been for several years the subject of study at the request of United Engineering Trustees, Inc., by Institute members specializing in lighting. Increased daytime use of film and slide projection had been hampered by daylight filtering through roller shades and the interior illumination had been pronounced obsolete, inadequate, and difficult to maintain. In an effort to improve the building facilities for their Founder Societies and associates, the board of trustees of United Engineering Trustees, Inc., undertook the modernization of this meeting hall and authorized the replacement of the false skylights with a more permanent boarding and a thoroughly modern lamp system.

The old lighting installation consisted of 3 large and 6 smaller false skylights above which were mounted a total of 692 25-watt lamps giving an average of one half foot-candle. Access for maintenance to the skylights was through the ducts of the ventilating system, by no means an easy task. Requirements for the renovation were: lighting equipment designed for ease of maintenance both in relamping (to be done from the floor—the auditorium is 42 feet high and has a balcony on three sides) and elimination of dust-catching nonessentials; of a design which would be in harmony with the archi-

The front cover of this issue shows the auditorium of the Engineering Societies Building with its new illumination.

S. W. Bruun is an illuminating engineer with the Rambusch Decorating Company, New York, N. Y.

Table I. Comparison of Old and New Lighting in the Engineering Societies Auditorium

Lighting	Total Watts
Old installation	
9 false skylights (692 25-watt lamps)	17,450
6 wall brackets (18 25-watt lamps)	450
Total	17,900
Average illumination 1/2 foot-candle	
New installation	
4 Rambusch Annulites (300-watt silver-bowl lamps) } 16 Rambusch Annulites (150-watt silver-bowl lamps) }	3,600
10 wall brackets (75-watt lamps)	750
Total	4,350
Average illumination 8 foot-candles	

tecture of the room; and an efficiency which would deliver more light and at the same time be more economical in current consumption.

Downlighting, in combination with a moderate amount of indirect lighting, was accepted as the solution and a series of Rambusch Annulites, a highly efficient form of downlighting unit, was installed in the plasterboard panels which replaced the glass skylights. The majority of the Annulites are totally recessed and can be relamped from the balcony by means of lamping rods. Four semiexposed 300-watt units which light the main seating area are equipped with automatic cutouts and can be lowered to the floor. The Annulites are all metal. The light is projected through an annular aperture from precision reflectors plated with pure gold. The indirect lighting is supplied by wall urns of appropriate design mounted on wall panels and balcony front. No changes were made in the stage and under balcony lighting.

Against the one half foot-candle average of the old lighting installation the new installation furnishes an average of 8 foot-candles. The accompanying table shows some interesting factors about the old and new lighting. With one quarter the consumption of the old installation, the new lighting has improved the illumination 16-fold and the efficiency 6,400 per cent.

Organic Plastics as Insulating Materials

JOHN DELMONTE
ASSOCIATE AIEE

Recent developments in new types of plastics and improved manufacturing techniques of older types are enabling these materials to assume an increasingly important role in the field of electrical insulation. Their electrical characteristics are reviewed here.

ORGANIC-plastic materials are playing increasingly prominent roles as solid dielectric materials. Their new importance is marked by recent developments of new types of plastics, as well as by improved processing and manufacturing techniques of earlier types. Familiarity with electrical properties of plastics and forms in which they are made available is of considerable advantage to electrical engineers concerned with insulating problems.

While plastic materials are contributing to the high quality of electrical insulation, the plastics industry is in a like measure indebted to the electrical industry for the semiautomatic and fully automatic control features of the most recent types of molding machines. The more progressive custom molders of plastics recognize the need for skilled electrical engineers in designing and maintaining these equipments so necessary for efficient production.

Types of plastics with respect to their origin, the particular significance they have in the electrical field, and representative trade names of plastics are indicated in Table I.

A further classification for plastic materials other than that appearing in Table I is based upon the response of the materials to thermal influences. The two major groups are:

Thermoplastic. Capable of being softened by heat and pressure an indefinite number of times.

Thermosetting. A material which undergoes chemical and physical changes to become permanently infusible and insoluble.

VARIOUS FORMS IN WHICH PLASTICS ARE AVAILABLE

As electrical insulating materials, plastics are made available in various forms:

Molded. The largest portion of plastic materials are molded under heat and pressure from a granular or powdered form to a solid body combining good physical and electrical properties. Metal inserts are often included in the assembly during molding to obtain a composite body in one operation.

Laminated. Aside from molded forms, the laminates are best known as insulating materials. Phenolic-resin impregnated paper or cloth bases are laminated under heat and pressure to form standard-size sheets, rods, and tubes. Representative electrical insulation fabricated from these are shown in Figure 1. Terminal strips, washers, radio tube bases, or any insulation combining high

John Delmonte is technical director of the Plastics Industries Technical Institute, Los Angeles, Calif.

Table I

Material	Representative Trade Names	Representative Electrical Applications or Properties
Synthetic resins		
Phenol or cresol formaldehyde	Bakelite, Durez, Textolite, Micarta, Insurok, Formica, Synthane, Makalot	Molded and laminated electrical equipments of every description. Enjoys the greatest consumption among plastics
Urea or thiourea formaldehyde	Plaskon, Beetle	Light-colored, decorative characteristics
Melamine-formaldehyde	Melmac	Newer composition possessing good dielectric properties
Glyceryl phthalates	Alkyds, Glyptals	Insulating lacquers of every description
Polymethyl methacrylate	Lucite, Plexiglas	Good insulation properties—transparent enclosures
Polystyrene	Styrene, Styrol	Best dielectric properties
Polyvinyl chloride-acetate	Vinylite	Excellent dielectric properties
Polyethylene		Excellent dielectric properties
Polyvinyl formal	Formes	Electric wire insulation
Polyvinyl chloride	Koroseal, Flamenol	Electric wire insulation
Cellulose Derivatives		
Cellulose nitrate	Celluloid	High flammability
Cellulose acetate	Tenite I, Plastacele, Lumarith, Vuepak	Various insulating foils and molded shapes
Cellulose acetate-butyrate	Tenite II	Various molded and extruded forms in electrical applications
Ethyl cellulose	Ethocel	Good insulating properties. Foils and lacquer
Natural Resins and Proteins		
Rosin, copal, amber, dammar gum		Useful as modifying agents in lacquer formulas
Bitumen	Cetec, Gilsonite	Cold molded insulation, switch plates, arc-resisting parts
Lignin		Various insulating panels and boards
Casein, zein, soybean protein		Various uses as surface coatings and adhesive agents

mechanical strength with good dielectric properties are best prepared from laminated plastics.

Films or Foils. Thin insulating films or foils, prepared from solutions of plastic materials, may be used in motor insulation, wrapped capacitor construction, or wire insulation. The materials may be applied on a cloth or paper base or else as 100 per cent plastic. Ethyl cellulose, cellulose acetate, and polystyrene, best known in these forms, are available as foils ranging from 0.001 inch thick up.

Extruded. Plastics may be extruded in form of continuous conduits or insulating sleeves, or else applied directly over the outside of electric conductors. Extruded sleevings of polyvinyl resins are largely replacing varnished cambric tubings among electrical manufacturers. Possessing greater uniformity and superior dielectric properties, they retain their characteristics indefinitely. Substantially permanent flexibility and nonaging qualities are other reasons why plasticized polyvinyl chloride sheaths will replace much of the rubber insulation for wires.

Impregnating Varnishes. Various plastic materials derived from synthetic and natural resins and cellulose derivatives are used in treating metal and wood surfaces, or else final assemblies like wound motor armatures. Where good heat resistance, strength, and good dielectric properties are required, baked glyceryl phthalate (Glyptal), or cashew-nut shell oil-formaldehyde resins (Harvel), are used for impregnating purposes. Plasticized thermoplastic

Table II. Electric Properties of Plastics

Material	Dielectric Strength* (Volts Per Mil)	At 1,000 Kilocycles: Power Factor (Per Cent)	At 1,000 Kilocycles: Loss Factor (Average)
Phenol formaldehyde:			
Wood-flour-filled, molded	300–500	3.5–6.0	0.1–0.5
Low-loss types, molded	200–400	0.7–0.8	0.03
Paper base, laminated	400–1,200	3.0–5.0	0.1
Fabric base, laminated	200–600	2.0–8.0	0.2
Asbestos base, laminated	100–300	15–20	0.8
Urea formaldehyde, molded	400–600	2.8	0.05
Polyvinyl chloride-acetate, filled	350–400	1.7	0.2
Methyl methacrylate, molded	170–500	1.5	0.045
Polystyrene, molded	500–700	0.01	0.0002
Polyvinyl formal		2	0.058
Polyvinyl chloride		1.7	0.056
Rubber		0.6	0.0025
Cellulose acetate sheet	600–950	3–4	0.030
Isolantite	300–500	0.4	0.025
Fused quartz		0.0022	0.00009
Electrical glass		0.60	0.057

* Dependent on thickness and temperature.

Table III. Comparative Dielectric Strengths

ASTM 60-Cycle Tests on 1/10-Inch Materials

Laminated Phenolic Material	Dielectric Strength: Short-Time, 25 C	Short-Time, 100 C	Step-by-Step, 25 C	Step-by-Step, 100 C
Paper (*X, XX*)	700	500	500	350
Asbestos (*A*)	225	100	135	75
Light-weave fabric (*LE*)	500	400	300	200
Heavy-weave fabric (*CE*)	500	400	300	200

formulas are also valuable, though dielectric properties suffer sometimes through plasticizer additions.

Cast Forms. Less frequently heard of, though becoming increasingly important, are cast forms of organic plastics. Phenolics and melamine formulas are available, the latter possessing superior dielectric properties. Small productions are being fulfilled by cast articles, benefiting from the absence of expensive steel molds ordinarily required for molding.

ELECTRICAL PROPERTIES OF PLASTICS

Electrical properties of plastics are dependent upon the conditions of manufacture as well as the conditions of service, and, in order to apply plastics intelligently, disadvantages as well as advantages should be studied.

Dielectric Strength. Representative values of dielectric strength of plastics are shown in Table II.[1] These are typical test values (American Society for Testing Materials) upon discs four inches in diameter and one-eighth inch thick. At thicknesses of 0.001 inch or thereabouts, thin foils from plastics show a marked dependence of kilovolts per mil upon material thickness. Doctor Bass first reported a peak in the curve for ethyl cellulose[2] which is reproduced in Figure 2. Values of 3,000 to 4,000 volts per mil are not uncommon for polystyrene, ethyl-cellulose, and cellulose acetate foils about 0.001 inch thick.

The high values of dielectric strength ranging from 3,000 to 4,000 volts per mil for thin foils are of fundamental importance to capacitor manufacturers, because they will permit the introduction of greater capacitance in a given volume, without decreasing the test breakdown-voltage requirements.

Most plastic materials are affected more or less by temperature and by moisture. Dielectric strength may be expected to show some variation in this direction. Representative values for thermosetting laminated phenolics are given in Table III for two different temperatures, 25 degrees centigrade and 100 degrees centigrade. Specific data on methods of test are outlined in the ASTM Specification *D*-149-36*T*. Short-time dielectric-strength step-by-step methods of test, and endurance dielectric-strength methods anticipate probable service conditions. Short-time test methods, giving highest values, are preferred and most frequently employed in applying routine proof tests to electric appliances.

In general, organic plastics do not offer much difficulty with respect to dielectric strength, because if there is ample wall thickness to meet mechanical requirements, there is generally more than adequate material to offer sufficient resistance to penetration by high voltages. In fact, any difficulty encountered in these respects is largely due to:

1. Faulty design.
2. Imperfections arising during manufacture.
3. Foreign matter in the plastic.

For example, dielectric breakdown over the surface is much more common than through the material. This is more often a problem of design. As for faulty manufacture, it is well known that cracks or breaks in molded plastics contribute to dielectric failure, rather than the material itself. This point has become even more significant in recent years in connection with injection-molded articles. The writer has observed in numerous injection-molded coil bobbins that the dielectric strength of a plastic material is substantially lower in the vicinity of a weld mark at which there exists a nonhomogeneous blend of molding material.

Plastic materials are often modified with reagents, known as fillers and plasticizers, for the purpose of improving physical properties such as impact strength and toughness. However, the fact must not be overlooked that in attaining these properties dielectric qualities may be sacrificed. It is well known, for example, that most plasticizers will substantially reduce the dielectric strength of the pure plastic. In most cases a compromise must be reached between electrical and mechanical properties.

Certain transparent plastic materials also lend themselves to the analysis of electrical breakdown in solid dielectric *prior* to the actual failure. In Figure 3 a section through a transparent plastic with electrodes spaced at a fixed distance is shown. As the voltage is raised, a point is reached where a stress pattern is formed (when viewed in polarized light), giving evidence of mechanical failure before electrical breakdown, which may be seen in the last stage. There a carbonized path has burned through the material. This photodielectric method of analysis is comparable to the photoelastic method of studying mechanical structures, with the aid of transparent plastics and polarized light. This technique has recently been developed by the author for observing visually dielectric breakdown.

Insulation Resistance. Plastics, like other insulating materials, exhibit a high resistance to the passage of electric currents. Whereas the resistance of a good metal conductor may be of the order of 10^{-6} ohm-centimeter, the resistance of a good insulator will be of the order of 10^{16} ohm-centimeters. Such quantities are difficult to measure with a high degree of accuracy, and the variations in insulation resistance over a given sample of material are usually of such magnitude as to obviate the development of more accurate instruments. Measurement may be broken down into volume and surface resistance, described as follows:

Insulation resistance between two electrodes is the ratio of the

Figure 1. Representative electrical insulation parts fabricated from laminated phenolic plastics

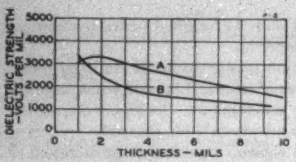


Figure 2. Dielectric strength as a function of thickness of Ethocel

Short-time ASTM 149-36T data by Bass-Goggin

A—3 days at 21 degrees centigrade; 50 per cent relative humidity

B—24 hours at 22 degrees centigrade in water

voltage applied to the electrodes to the total current that leaks between them.

Volume resistance is a measure of the ratio of applied electromotive force across a volume of insulating material to the current that flows only through this volume.

Representative values of insulation resistance are given in Table IV. Quite outstanding are plastic materials like polystyrene. Problems of insulation resistance are of vital concern to all electrical manufacturers, where electrical leakage may affect the serviceability of the apparatus. However, the engineer may not rely fully upon data such as appear in Table IV. Temperature exerts quite a decided influence upon insulation resistance, as the curves in Figure 4 will illustrate. These data were taken from a paper by Doctor Zinzow.[4] Of particular interest is a molding compound like *BM*-262, developed for its good dielectric properties. It is a considerably better dielectric than some of the general-purpose molding. When excellence in dielectric properties is desired, it is better to consult the materials manufacturer rather than make a random choice.

Surface insulation resistance depends a great deal upon manufacturing conditions as well as operating environment. The highest resistance values observed in plastics are those in which a good surface gloss and low water absorption are evident. Dull uneven surfaces will accumulate dirt and dust impurities, and the surface resistance of molded or laminated parts will drop sharply.

There are certain conditions under which a low surface insulation resistance may be desired, as on aircraft, where plastic enclosures are to derive the benefit of electrostatic shielding. Various methods have been worked out for electroplating the surface of plastics. In these combinations there are singular advantages in the integral assembly of a continuous metal shield and a plastic material as base.

Arc Resistance. Not too much data exist on the arc resistance of various plastics. An ASTM testing specification (*D*495-38*T*) suggests arcs of known current and

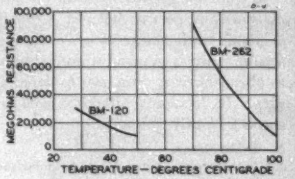


Figure 4. Influence of temperature on insulation resistance

Data by Zinzow

controlled frequency to induce failure. Materials such as phenolics are relatively poor performers in the presence of power arcs. These materials will carbonize fairly readily, and, once the carbonized path has been established, the material has lost its usefulness as an insulator. However, thermoplastic materials such as acrylates, polystyrene, and cellulose derivatives will be scarred across their surfaces by intense arcs, but their continued usefulness is not generally impaired.

Good arc-resisting properties are possessed by cold-molded bitumen-base plastics and shellac plastics. The former possess high water absorption and low surface insulation resistance, but nevertheless are outstanding in their resistance to arcs. Switch and circuit breakers

Figure 3. Photodielectric analysis of a section through a transparent plastic with electrodes spaced at a fixed distance

One-fourth-inch gap — *One-eighth-inch-diameter rod*

A—At start—zero voltage *B—To 8,700 volts in 5 seconds and return* *C—To 10,800 volts in 5 seconds and return* *D—To 12,100 volts in 5 seconds and return* *E—Failure at 13,000 volts within 3 to 2 seconds*

Table IV. Insulation Resistance of Insulating Materials

25 Degrees Centigrade

Material	Ohm-Centimeters
Phenol formaldehyde	10^{10}–10^{12}
Urea formaldehyde	10^{13}
Methyl methacrylate	10^{14}
Polyvinyl chloride acetate	10^{14}
Cellulose acetate	10^{12}
Polystyrene	10^{17}–10^{18}
Rubber	10^{14}–10^{16}
Glass	10^{14}
Fused quartz	10^{18}

frequently employ these materials, as well as vulcanized fiber, for effective general-purpose type of insulation. For high-strength plastics combining good dielectric properties the laminates are quite acceptable.

Dielectric Constant. The dielectric constant of most plastic materials does not vary much over the range of available frequencies, except in certain examples where polarization effects at interfaces of fillers and resin molecules become high. In general, nonpolar molecules such as polystyrene do not vary much in dielectric constant when varying from lower frequencies to high radio frequencies. Table V outlines representative dielectric constants for different plastics; the data was collected from various sources.

While low values of dielectric constants are not of much significance to capacitor manufacture, changes in these constants are quite important to theoretical analyses of the plastic materials. For example, plastics with definite polar properties have been shown by Morgan and Yager to have dielectric constants varying with frequency.[5] A portion of their curves is reproduced herewith (Figure 5). For comparison purposes, nonpolar molecules of polystyrene and polyethylene are included. It is also interesting to observe that nonpolar molecules appear to have lower dielectric constants.

Dielectric constants depend not only upon temperature

Table V. Representative Dielectric Constants

Material	At 60 Cycles	At 1,000 Cycles	At 1,000 Kilocycles
Phenol formaldehyde:			
Molded, mineral	5–20	5–20	5–20
Molded, wood-flour-filled	4.5–12	4–8	4.5–8
Molded, fabric-filled	5–10	4.5–6	4.5–6
Laminated, paper base			4.5
Laminated, fabric base	5–7		4.5–6
Phenol furfural, molded	4–7.5		5–7.5
Urea formaldehyde, molded	7	6.4	5.8
Polystyrene	2.6	2.6	2.6
Cellulose acetate	5–7.5	6.8	4.2–6.2
Cellulose nitrate	6.7–7.3	6–7	6.1
Polyvinyl chloride-acetate		3.1	2.9
Methyl methacrylate	3.4	3.1	2.8
Ethyl cellulose	2.9–3.3	3.2	3.2
Polyvinyl chloride		3.2	2.9
Rubber hydrochloride		2.5	2.5
Chloroprene		7.8	6.7
Shellac	3.1		
Isolantite		6.1	6
Fused quartz		4.1	4.1
Hard rubber	2.8	2.9–3.1	3.1
Air	1	1	1

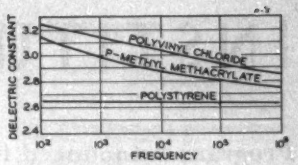


Figure 5. Dependence of dielectric constant on frequency

Data by Fuoss

and frequency but also the composition. Considerable time has been spent by Doctor Fuoss in investigating plasticized polyvinyl-chlorides.[6] His data indicate higher dielectric constants for increasing proportions of tricresyl phosphate plasticizer in proportion to the polyvinyl resin. Much valuable research is in progress in this field in an effort to ascertain fundamental relationships between chemical structures and electrical properties.

Power Factor. Of paramount concern to radio and wireless engineers are the power factors of the insulating materials. As a measure of the power absorbed by the material in an a-c field, the power factor is a convenient means of differentiating between the various plastics. Considering all types of insulating materials, several plastics are quite outstanding in their low power factors. Polystyrene, polyethylene, and "low-loss" phenolics behave well in this connection.

The power factors and loss factors of plastics must be considered not only in the light of their observed values at room temperature but also under service conditions where they are subject to mechanical and temperature stresses. It is imperative in specifying and applying plastics that full importance be attached to these details if their application is to prove successful.

Precision capacitors, coil forms, and insulator supports may be molded of a "low-loss" phenolic which is prepared from a high mica-filler content. Outwardly, molded articles from this grade of material are characterized by a yellow-brown color. In some equipments, molded polystyrene insulating parts are preferred. These plastics are also available in lacquer form which may be applied to the outside of insulating bushings for electric connections.

The presence of water or conducting impurities in the dielectric tends to yield higher power factors. In general, the better insulating materials among the plastics are those possessing the lowest water absorption. Polystyrene with practically zero water absorption is best among the insulating materials.

REFERENCES

1. Plastics in Engineering (second edition), **John Delmonte.** Penton Publishing Company, Cleveland, Ohio, 1942.
2. American Society for Testing Materials Standard -D147-39T.
3. Preprint 74-36, **S. Bass, W. Goggin.** Electrochemical Society *Transactions*, October 12, 1938, page 559.
4. Paper presented at Museum of Science and Industry, **Zinsow.** April 1938.
5. **Morgan, Yager.** *Industrial and Engineering Chemistry*, volume 32, November 1940, page 1519.
6. **Fuoss.** *Annals* of the New York Academy of Science, volume 40, December 1940, page 429.

INSTITUTE ACTIVITIES

Program Announced for National Technical Meeting, January 25–29, 1943

Conservation of materials by getting the most out of existing equipment will be the particular objective as an aid to the war effort for the AIEE national technical meeting to be held in New York, N. Y., January 25–29, 1943. On Thursday, January 28, the Institute of Radio Engineers will hold a meeting concurrently in both morning and afternoon. In the evening a joint AIEE–IRE meeting will be held, at which there will be an address on "Ultra-high Frequencies" by Doctor G. C. Southworth of the Bell Telephone Laboratories, Inc. Both meetings will be held in the Engineering Societies Building. In accordance with AIEE wartime policies (*EE, Sept. '42, p. 477*) all programmed social activities have been omitted. It is hoped, however, that there will be opportunities for members and guests to get together during the meeting.

The general session will feature the important topic of "Technical Man Power Requirements As an Aid to the War Effort." Prominent speakers will present both the military and industrial phase of this subject.

MEDAL PRESENTATIONS

The Edison medal, John Fritz medal, and Hoover medal, will be presented on Wednesday evening, January 27.

The Edison medal was awarded to Major Edwin H. Armstrong (*this issue, p. 27*) "for distinguished contributions to the art of electric communication, notably the regenerative circuit, the superheterodyne, and frequency modulation."

As previously announced, the John Fritz medal was awarded to Doctor Willis R. Whitney (A '01) (*EE, Nov. '42, p. 574, 582*) "for distinguished research, both as an individual investigator and as an outstanding and inspiring administrator of pioneering enterprise, co-ordinating pure science with the service of society through industry."

The Hoover medal was awarded to Gerard Swope (F '22) (*EE, Nov. '42, p. 574–5, 582*) with the following citation: "engineer and distinguished leader of industry, ever deeply interested in the welfare of his fellowmen, whose constructive public service in the field of social, civic, and humanitarian effort has earned for him the Hoover medal for 1942."

TECHNICAL SESSIONS AND CONFERENCES

To carry out the principal theme of conservation of materials by good engineering practice three more proposed guides have been developed in co-operation with the standards committee. These guides are in addition to the guide for overloading transformers and voltage regulators (AIEE *Transactions, volume 61, 1942, September section, pp. 692–7*). They treat the selection of electric motors and motor controllers, recommendations for application and operation of circuit breakers and switchgear, and industrial power distribution systems. Each proposed guide will be presented and discussed in a separate conference on respective subjects. In addition, two other memoranda dealing with emergency measurements to increase output of generating equipment and generating systems will be presented and discussed in a conference on power generating equipment. It is expected that these memoranda will later be put into the form of reports for issuance as guides at a subsequent meeting.

Other sessions and conferences which will have to do with getting the most out of existing equipment deal with capacitor generators and transformer loading, emergency loading of transmission systems, emergency rating of power cables, electronic tubes, and substation designs to meet wartime conditions. Others which are planned as aid to the war effort deal with defense lighting, wartime engineering education, transformer loading, and analysis of military loads and postwar application.

REGISTRATION AND HOTELS

All AIEE members who have received an advance registration card should fill in and mail the card promptly. Upon arrival at the meeting a member who registered by mail should not fill in another card, just obtain a badge. A separate registration will be conducted for the IRE meeting but IRE members are cordially invited to attend any AIEE sessions and AIEE members are likewise invited to attend IRE sessions. A registration fee of $2 will be charged all nonmembers except Enrolled Students, the immediate families of members, and those attending the IRE meetings. Hotel reservations should be made by writing directly to the hotel preferred.

COLUMBIA ENGINEERS' DINNER

The annual informal dinner for Columbia electrical engineers will be held Wednesday evening, January 27, at the Columbia University Club, 4 West 43d Street. A social half hour will precede the dinner, which is scheduled for 6:30 p.m.

COMMITTEE

The personnel of the committee making arrangements for the 1943 meeting is:

C. R. Jones, *chairman* (M '30), F. A. Cowan (M '29), W. S. Hill (M '30), M. D. Hooven (M '30), A. E. Knowlton (M '30), C. S. Purnell (M '35), R. L. Webb (M '35), C. C. Whipple (M '26).

Summarized Schedule of Principal Events

Monday, January 25

9:00 a.m.	Registration
9:30 a.m.	Capacitor generators and transformer loading
9:30 a.m.	Relaying
9:30 a.m.	Electrical machinery
2:00 p.m.	Transmission lines
2:00 p.m.	Conference on relays
2:00 p.m.	Conference on selection of motors and controllers
7:30 p.m.	Conference on emergency loading of transmission systems

Tuesday, January 26

9:30 a.m.	Transmission and distribution
9:30 a.m.	Land transportation
9:30 a.m.	Industrial power applications
2:00 p.m.	Relaying on long transmission lines
2:00 p.m.	Conference symposium on defense lighting
2:00 p.m.	Basic sciences
2:00 p.m.	Conference on emergency rating of power cables

Wednesday, January 27

10:00 a.m.	General session
2:00 p.m.	Conference on wartime engineering education
2:00 p.m.	Conference on getting the most out of electronic tubes in wartime
2:00 p.m.	Conference on substation designs to meet wartime conditions
8:15 p.m.	Medal presentations

Thursday, January 28

9:30 a.m.	IRE technical session
9:30 a.m.	Circuit breakers and switches
9:30 a.m.	Conference on power generating equipment
2:00 p.m.	IRE annual business meeting
2:00 p.m.	Switching equipment and related subjects
2:00 p.m.	Conference on industrial distribution
8:30 p.m.	AIEE–IRE meeting

Friday, January 29

9:30 a.m.	Transformer loading
9:30 a.m.	Radio measurements
9:30 a.m.	Conference on analysis of military loads and postwar application
2:00 p.m.	Transformer loading discussion
2:00 p.m.	Conference on basic characteristics of varistors

Future AIEE Meetings

National Technical Meeting
New York, N. Y., January 25–29, 1943

District Technical Meeting
Pittsfield, Mass., April 8–9, 1943

District Technical Meeting
Kansas City, Mo., April 28–30, 1943

National Technical Meeting
Cleveland, Ohio, June 21–25, 1943

Tentative National Technical Meeting Program

Monday, January 25

9:30 a.m. Capacitor Generators and Transformer Loading

43-13. Steady-State and Transient Stability Analysis of Series Capacitors in Long Transmission Lines. **J. W. Butler, J. E. Paul, T. W. Schroeder,** General Electric Company

43-8. Self-Excited Oscillations of Capacitor-Compensated Long-Distance Transmission Systems. **R. B. Bodine, C. Concordia, G. Kron,** General Electric Company

43-16. Mobile Capacitor Units for Emergency Loading of Transformers in Open Delta. **H. B. Wolf, G. G. Mattison,** Duke Power Company

43-25. Kilowatts, Kilovars, and System Investments. **J. W. Butler,** General Electric Company

43-45. Open-Delta Transformer Banks—Analysis of Circuit. **J. E. Clem,** General Electric Company

43-48. Shunt Capacitors. General systems subcommittee of the committee on power transmission and distribution.

9:30 a.m. Relaying

43-27. Pilot-Wire Circuits for Protective Relaying—Experience and Practice. Relay subcommittee, committee on protective devices

43-15. A New Generator Differential Relay. **A. J. McConnell,** General Electric Company

43-28. The Effect of Current-Transformer Residual Magnetism on Balanced-Current or Differential Relays. **H. T. Seeley,** General Electric Company

43-5. Correlation of System Overvoltages and System-Grounding Impedance. Working group on correlation of system-grounding impedance

9:30 a.m. Electrical Machinery

43-2. A Useful Equivalent Circuit for a Five-Winding Transformer. **L. C. Aicher, Jr.,** Allis-Chalmers Manufacturing Company

43-3. A New Type of Adjustable-Speed Drive for Alternating-Current Systems. **A. G. Conrad, S. T. Smith, P. F. Ordung,** Yale University

43-4. Performance Calculations on Tapped-Winding Capacitor Motors. **P. H. Trickey,** Diehl Manufacturing Company

43-6. Analysis of Rating Methods for Intermittent Loads. **R. E. Hellmund** (deceased) formerly with Westinghouse Electric and Manufacturing Company

43-47. Factors Affecting the Design of D-C Magnets. **L. T. Rader,** General Electric Company

2:00 p.m. Transmission Lines

43-7. Abnormal Overvoltages Caused by Transformer Magnetizing Currents in Long Transmission Lines. **H. A. Peterson, T. W. Schroeder,** General Electric Company

43-21. Wood-Pole 230-Kv Transmission Lines. **O. S. Clark,** United States War Department

43-29. Transmission-Line and System Problems in Supplying Large Electric Arc Furnaces During Wartime. **B. M. Jones,** Duquesne Light Company

43-22. Ampere Load Limits for Copper in Overload Limes. **A. H. Kidder, C. B. Woodward,** Philadelphia Electric Company

43-20. Intrasystem Transmission Losses. **E. E. George,** Ebasco Services, Inc.

2:00 p.m. Conference on Relays

Introduction: H. F. Lindemuth

CP.* Acceptance Tests and Installation Tests. **S. C. Leland,** Westinghouse Electric and Manufacturing Company

● PAMPHLET reproductions of authors' manuscripts of the numbered papers listed in the program may be obtained as noted in the following paragraphs.

● ABSTRACTS of most papers appear on pages 27–34 of this issue and pages 619–20 of the December 1942 issue.

● PRICES and instructions for procuring advance copies of these papers accompany the abstracts. Mail orders are advisable, particularly from out-of-town members, as an adequate supply of each paper at the meeting cannot be assured. Only numbered papers are available in pamphlet form.

● COUPON books in $5 denominations are available for those who may wish this convenient form of remittance.

● THE PAPERS regularly approved by the technical program committee ultimately will be published in "Transactions"; many will appear in "Electrical Engineering."

CP.* Calibration Tests. **J. C. Bowman,** Public Service Electric and Gas Company

CP.* Routine Tests, Inspection, and Trouble Checks. **C. A. Muller,** American Gas and Electric Service Corporation

CP.* Reports and summary. **J. H. Oliver,** General Electric Company

CP.* Report from the working group on war activities. **L. F. Kennedy,** General Electric Company

2:00 p.m. Conference on Selection of Motors and Controllers

43-62. Proposed Guide for the Selection of Electric Motors and Motor Controllers. Report of committee on electrical, machinery, committee on industrial power applications (Applies to American Standard C50, "Rotating Electrical Machinery," and AIEE Standard 15, "Industrial Control Apparatus")

The conference session will consist of a number of prepared discussions of conference papers on various aspects of the guide. There also will be opportunity for open discussion on the guide.

7:30 p.m. Conference on Emergency Loading of Transmission Systems

Tuesday, January 26

9:30 a.m. Transmission and Distribution

43-10. Dielectric Recovery Characteristics of Large Air Gaps. **G. D. McCann, J. J. Clark,** Westinghouse Electric and Manufacturing Company

43-12. Impulse and 60-Cycle Characteristics of Driven Grounds—III, Effect of Lead in Ground Installation. **P. L. Bellaschi, R. E. Armington,** Westinghouse Electric and Manufacturing Company

43-26. Harmonics and Load Balance of Multiphase Rectifiers—Considerations in the Selection of the Number of Rectifier Phases. **R. D. Evans,** Westinghouse Electric and Manufacturing Company

43-30. Pulling Loads on Single- and Multiple-Conductor Impregnated-Paper Lead-Encased Cable, Solid Type. **A. P. S. Bellis, John A. Roebling's Sons** Company

43-23. Electrical Stability of Electrical-Insulating Oils Under Limited Oxidation. **J. C. Balsbaugh, A. G. Assaf,** Massachusetts Institute of Technology

43-34. Metering Power on the Low-Voltage Side. **A. J. Petzinger, B. E. Lenehan,** Westinghouse Electric and Manufacturing Company

9:30 a.m. Land Transportation

CP.* The Sorocabana Railway Electrification. **Durval Muylaert,** Sorocabana Railway

CP.* Train Communication. **L. O. Grondahl, P. N. Bossart,** Union Switch and Signal Company

43-33. Keep Them Rolling. **J. W. Teker,** General Electric Company

43-49. Factor Involved in the Selection of Railroad Motive Power. **H. C. Wilcox, A. G. Oehler,** *Railway Age*

9:30 a.m. Industrial Power Applications

43-17. Paired-Phase Busbars for Large Polyphase Currents. **L. E. Fisher, R. L. Frank,** Bull Dog Electric Products Company

43-41. The Power-Recovery System of Testing Aircraft Engines. **G. E. Cassidy, W. A. Mostoller, W. L. Wright,** General Electric Company

43-31. Synchronous Motors With Controlled Excitation for Suddenly Applied Loads. **W. K. Boice, B. H. Caldwell, M. N. Halberg,** General Electric Company

2:00 p.m. Relaying on Long Transmission Lines

43-19. Switching Overvoltage Hazard Eliminated in High-Voltage Oil Circuit Breakers. **L. F. Hunt,** Southern California Edison Company, Ltd.; **E. W. Boehne, H. A. Peterson,** General Electric Company

43-37. Performance Requirements for Relays on Unusually Long Transmission Lines. **F. C. Poage, C. A. Stroifus, D. M. MacGregor, E. E. George,** Ebasco Services, Inc.

43-38. Protective Relaying for Long Transmission Lines. **A. R. VanC. Warrington,** General Electric Company

43-39. Staged-Fault Tests of Relaying and Stability on Kansas–Nebraska 270-Mile 154-Kv Interconnection. **C. W. Minard, E. A. Swanson,** Nebraska Power Company; **R. B. Gow, W. A. Wolfe,** Kansas Gas and Electric Company

2:00 p.m. Conference Symposium on Defense Lighting

This is one of a series of conferences sponsored by the committee on production and application of light to present up-to-the-minute defense lighting activities and developments from both the military and civilian points of view.

Tom P. Walker, president of Council of Electric Operating Companies, Washington, D. C.

Richard E. Simpson, chairman, dimout counsulting committee, State Defense Council, Conn.

Lieutenant Colonel B. W. Beers, executive officer, Operating and Training Division, Headquarters Second Service Command, Governors Island, N. Y.;

* CP: Conference paper; no advance copies are available; not intended for publication in *Transactions*.

Tentative National Technical Meeting Program (Continued)

Major R. P. Breckenridge, Corps of Engineers, Camouflage Branch, United States Army, Fort Belvoir, Va.

2:00 p.m. Basic Sciences

43-11. Formulas for the Calculation of the Inductance of Linear Conductors of Structural Shape. **T. J. Higgins,** Illinois Institute of Technology

43-50. Generation of Electric Charges by Moving Rubber-Tired Vehicles. **R. S. Mackown,** California Institute of Technology; **Victor Wouk,** Westinghouse Electric and Manufacturing Company

43-45. Skin Effect in Bimetallic Conductors **R. R. Teare, Jr., Josephine R. Webb,** Carnegie Institute of Technology

43-9. Equivalent Circuits for Oscillating Systems and the Riemann–Christoffel Curvature Tensor. **Gabriel Kron,** General Electric Company

2:00 p.m. Conference on Emergency Rating of Power Cables

Wednesday, January 27

10:00 a.m. General Session

Presentation of Alfred Noble Prize to George W. Dunlap

Technical Man Power As an Aid to the War Effort

2:00 p.m. Conference on Wartime Engineering Education

CP.* Continuing Programs of Specialized Engineering Education for Military and Industrial Services, and the Allocation of the Technical Graduates. **Edward C. Elliott,** chief, professional and technical employment and training division, War Manpower Commission, and president, Purdue University

CP.* Accelerated Programs of Specialized Engineering Education Versus the Short Specialized Types of Training. **Henry T. Heald,** president, Society for the Promotion of Engineering Education, and president, Illinois Institute of Technology

CP.* The Increasing Need of Engineering Graduates in Industry During a Prolonged War Period. **Maynard M. Boring,** apparatus design engineering department, General Electric Company

Announcement: A meeting of the committee on education will directly follow this session.

2:00 p.m. Conference on Getting the Most Out of Electronic Tubes in Wartime

This conference will take the form of an informal discussion on methods of operating electronic devices to improve their life and increase their usefulness under existing wartime conditions. The question of adequate rating of electronic devices to permit the obtaining of their maximum utility will also be considered. Several speakers will introduce briefly these topics, after which discussion from the floor will be in order. It is hoped to obtain a wide participation by those present.

2:00 p.m. Conference on Substation Designs to Meet Wartime Conditions

Thursday, January 28

9:30 a.m. IRE Technical Session

9:30 a.m. Circuit Breakers and Switches

43-32. An Improved Axial Air-Blast Interrupter for Severe Operating Duty. **P. L. Taylor, H. W. Martin,** Allis-Chalmers Manufacturing Company

43-44. A New 50,000-Kva—5-Kv Oilless Circuit Breaker and Metal-Clad Switchgear Unit. **R. C. Dickinson, B. L. Hayford,** Westinghouse Electric and Manufacturing Company

43-51. A Vertical-Flow Compressed-Air Circuit Breaker and Its Application on a 132-Kv Power System. **H. A. P. Langstaff,** West Penn Power Company; **B. P. Baker,** Westinghouse Electric and Manufacturing Company

43-52. The Auto-Blast Interrupter Switch. **E. A. Williams, Jr., W. G. Harlow,** General Electric Company

43-53. A Multiorifice Interrupter for High-Voltage Oil Circuit Breakers. **L. R. Ludwig, W. M. Leeds,** Westinghouse Electric and Manufacturing Company

9:30 a.m. Conference on Power Generating Equipment

The objective of this conference is to correlate all possible ideas on how to get the most out of present equipment.

CP.* Emergency Measures to Increase Output of Generating Equipment. **C. M. Laffoon,** subcommittee chairman

CP.* Emergency Measures to Increase Output of Generating Systems. **R. P. Crippen,** subcommittee chairman

CP.* Wartime Personnel Problems

The first memorandum will contain case examples of the effect of voltage, ambient temperature, hydrogen pressure, and so forth, on the operation of turbine and waterwheel generators. The second memorandum is being prepared from answers to a questionnaire submitted to the leading operating companies together with summation on such subjects as loading limits on equipment, maintenance, power-factor correction, interconnected operation, effect of voltage and frequency on system loads, rebuilding or rehabilitation of equipment or stations, and so forth. The two memoranda are intended to serve as a basis for questions and discussions from the audience, to which the major part of the conference will be devoted.

2:00 p.m. IRE Annual Business Meeting

2:00 p.m. Switching Equipment and Related Subjects

43-54. Oil-Impregnated Paper High-Voltage Condenser Bushings for Circuit Breakers and Transformers. **H. J. Lingal, H. L. Cole, T. R. Watts,** Westinghouse Electric and Manufacturing Company

43-35. The Cathode-Ray Oscillograph Applied to Long-Time Switching Transients. **G. W. Dunlap, N. Rohats,** General Electric Company

43-63. Application of Lightning Protective Devices in Wartime. **L. W. Gross,** American Gas and Electric Service Corporation

43-55-ACO†. Preliminary Report on Guides for Application and Operation of Circuit Breakers and Switchgear. Subcommittee on circuit breakers, switches, and fuses, committee on protective devices.

2:00 p.m. Conference on Industrial Distribution

43-40-ACO.† A Proposed Wartime Guide for Industrial Power Distribution Systems. Interim report of committee on industrial power applications

8:30 p.m. IRE–AIEE Meeting

Address: "Ultrahigh Frequencies." Doctor **G. C. Southworth,** Bell Telephone Laboratories, Inc.

*CP: Conference paper; no advance copies are available; not intended for publication in *Transactions*.

†ACO: Advance copies only available; not intended for publication in *Transactions*.

Friday, January 29

9:30 a.m. Transformer Loading

43-56. Cooling Power Transformers by Forced Circulation of Cooling Medium. **K. K. Palmer, L. H. Burnham,** General Electric Company

43-18. Equivalent Ambient Temperatures for Loading Transformers. **W. C. Sealey,** Allis-Chalmers Manufacturing Company

43-36. The Rating of Power Transformers As Determined by the War Emergency. **R. J. Salsbury, A. F. Phillips,** Duquesne Light Company

43-24. Substation Transformer Emergency Overloading Practice. **L. W. Clark,** The Detroit Edison Company

9:30 a.m. Radio Measurements

43-14. An Electromechanical Calculator for Directional Antenna Patterns. **C. E. Smith,** United Broadcasting Company; **K. L. Gove,** North Hollywood, California

43-57. Measurements Pertaining to the Coordination of Radio Reception With Power Apparatus and Systems. **C. M. Foust, C. W. Frick,** General Electric Company

43-58. Effect of Radio Frequencies of a Power System on Radio-Receiving Systems. **C. V. Aggers, W. E. Pakala,** Westinghouse Electric and Manufacturing Company; **W. A. Stickel,** West Penn Power Company

43-1. An Instrument for the Determination of Contact Making and Breaking Time. **Walther Richter, W. H. Elliot,** Cutler-Hammer, Inc.

43-59. Insulation Testing of Electric Windings. **C. M. Foust, N. Rohats,** General Electric Company

9:30 a.m. Conference on Analysis of Military Loads and Postwar Application

43-60. Estimating Electric Loads for Military Training Bases, Federal Housing, and Other Wartime Projects. **H. M. Potts,** Bonneville Power Administration

H. P. Seelye and **D. K. Blake** will discuss the relationship of distribution to the general problem with emphasis on conservation possibilities

CP.* A Method of Analyzing Wartime Loads. **W. L. Tadlock,** The Commonwealth and Southern Corporation

CP.* Matters of Safety

1. To people; 2. In equipment design. **S. B. Williams**

R. B. Shepard will comment and **C. F. Scott** will discuss the relationship of ambient and operating temperatures to the problem of safety.

CP.* Wartime Electric Motors and Their Postwar Applications. **J. L. Hamilton,** Century Electric Company

43-61. Rural Electrification Engineering and Electroagricultural Engineering. **M. M. Samuels,** United States Department of Agriculture, Rural Electrification Administration

2:00 p.m. Transformer Loading Discussion

2:00 p.m. Conference on Basic Characteristics of Varistors

This résumé will cover various nonohmic devices, nonsymmetrical, such as copperoxide and other rectifier types, as well as the symmetrical, including the more recently developed thermistor types. It should be of considerable interest to all engineers. Authoritative speakers will initiate the discussion by presenting up-to-date information on the various types, such as their current voltage relationships, temperature and humidity effects, maximum voltage or power limitations, polarization and frequency effects, and minimum useful voltage.

AIEE Nominating Committee for 1942–43 Announced

The national nominating committee of the AIEE, in accordance with the Institute's bylaws, will meet during the national technical meeting to be held January 25–29, 1943, in New York, N. Y., to nominate national officers to be voted upon by the membership in the spring of 1943. Members of the national nominating committee are as follows:

Representing the board of directors

M. S. Coover, Iowa State College, Ames, Iowa.

Mark Eldredge, 2110 Spencer Road, Silver Spring, Md.

C. R. Jones, Westinghouse Electric and Manufacturing Company, New York, N. Y.

T. G. LeClair, Commonwealth Edison Company, Chicago, Ill.

E. T. Mahood, Southwestern Bell Telephone Company, Kansas City, Mo.

Representing the Ten Geographical Districts

1. A. G. Conrad, Yale Station DLE, New Haven, Conn.

2. B. Van Ness, Jr., Pennsylvania Water and Power Company, Baltimore, Md.

3. C. C. Whipple, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

4. Stanley Warth, Southern Bell Telephone and Telegraph Company, Jacksonville, Fla.

5. E. B. Paine, University of Illinois, Urbana, Ill.

6. Hubert Sharp, The Mountain States Telephone and Telegraph Company, Denver, Colo.

7. V. P. Hessler, University of Kansas, Lawrence.

8. Willis T. Johnson, California Electric Power Company, El Centro, Calif.

9. A. LeRoy Taylor, University of Utah, Salt Lake City.

10. C. A. Price, Canadian Westinghouse Company, Ltd., Hamilton, Ont.

Alternates:

4. J. P. Argo, 1478 Snowden Avenue, Memphis, Tenn.

5. J. A. Northcott, Jr., University of Notre Dame, Notre Dame, Ind.

6. H. B. Palmer, University of Colorado, Boulder, Colo.

8. Franklin F. Evenson, P. O. Box 1710, San Diego, Calif.

10. A. H. Frampton, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

Contents of December 1942 Supplement

Technical papers to supplement those published in the monthly Transactions sections of *Electrical Engineering* for July through December will appear in the December 1942 "Supplement to Electrical Engineering—Transactions Section." This supplement will contain seven papers, their discussions, and the discussions of technical papers published in the July—December monthly sections. The publication of this supplement completes the publication of papers and discussions presented at the 1942 AIEE North Eastern District meeting in Schenectady, N. Y., the 1942 AIEE summer convention in Chicago, Ill., and the 1942 AIEE Pacific Coast convention in Vancouver, B. C., Canada.

Copies of the supplement will be mailed shortly to those who entered advance orders. Other may obtain copies at 50 cents each from the AIEE order department, 33 West 39th Street, New York, N. Y., as long as the limited supply lasts.

Papers appearing in the December 1942 supplement, abstracts of which have been published in *Electrical Engineering* in advance of the Chicago and Vancouver conventions, are:

42-145—The Combination of Probability Curves in Engineering; *Roger I. Wilkinson (A'35).* Abstracted in July 1942 issue, page 362.

42-115—Emergency Overloading of Air-Cooled Oil-Immersed Power Transformers by Hot-Spot Temperatures; *V. M. Montsinger (F'29), P. M. Ketchum (A'30).* Abstracted in June 1942 issue, page 324.

42-112—Series Capacitors for Transmission Circuits; *E. C. Starr (F'41), R. D. Evans (F'40).* Abstracted in June 1942 issue, page 326.

42-103—Induced Voltages on Transmission Lines; *C. F. Wagner (F'40), G. D. McCann (A'38).* Abstracted in May 1942 issue, page 262.

42-111—Load Ratings of Cable—II; *Herman Halperin (M'26).* Abstracted in June 1942 issue, page 326.

42-117—Stability Study of A-C Power-Transmission Systems—I and II; *John Grzybowski Holm (M'29).* Abstracted in June 1942 issue, page 326.

42-90—Factors Which Influence the Behavior of Directional Relays; *T. D. Graybeal (A'38).* Abstracted in May 1942 issue, page 262.

Edwin Armstrong Awarded 1942 Edison Medal

Edwin Howard Armstrong, professor of electrical engineering at Columbia University, New York, N. Y., has been named the recipient of the Edison Medal, highest AIEE award, for the year 1942, "for distinguished contribution to the art of electric communication, notably the regenerative circuit, the superheterodyne, and frequency modulation." Presentation of the medal will take place at the AIEE national technical meeting, January 25–29, 1943.

Major Armstrong was born in New York, N. Y., on December 18, 1890, and received the degrees of electrical engineer in 1913 and doctor of science in 1929 from Columbia University. He was a protégé of Michael I. Pupin, past president of the AIEE and recipient of the Edison Medal in 1920, and worked closely with him on a number of research projects.

Major Armstrong's research on the operating properties of the audion detector resulted in his invention of the feedback or regenerative circuit which became the means not only of increasing the sensitivity of the audion as a detector of radio signals but also became the means of producing for the first time continuous high-frequency oscillations by means of a thermionic tube.

While serving in the United States Army in France during World War I, he made his second invention, the superheterodyne receiving system, which was destined to be another cornerstone in the development of the radio communication art. This system of receiving far surpassed any development up to that time and it is still the type of circuit used today in many radio receivers.

In 1922 came his development of the superregenerative circuit, a system of radio reception providing a means of increasing the sensitivity of a detector above that normally obtained. This receiving circuit supplied the principal means of exploring and developing the ultrashort-wave channels. In 1933 his development of wide-band frequency modulation was disclosed. This system is now recognized as the basis for an entirely new era in radiobroadcasting and communication.

Major Armstrong served as associate professor of research at Columbia University from 1914 to 1935, when he became professor of electrical engineering.

Among the honors received by Major Armstrong are the following: Medal of Honor of the Institute of Radio Engineers in 1917 for his work in developing regeneration; Chevalier de la Legion d'Honneur of the French Government in 1919; Eggleston Medal in 1939 at Columbia University; the Holley Medal of the American Society of Mechanical Engineers for 1940; the Franklin Medal of the Franklin Institute for 1941; and the John Scott Medal for 1942, awarded by the board of directors of City Trusts, Philadelphia, Pa.

ABSTRACTS • • •

TECHNICAL PAPERS previewed in this section will be presented at the AIEE national technical meeting, New York, N. Y., January 25–29, 1943, and are expected to be ready for distribution in advance pamphlet form within the current month. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters or at the convention registration desk.

Mail orders will be filled AS PAMPHLETS BECOME AVAILABLE

Basic Sciences

43-23—Electrical Stability of Electrical Insulating Oils Under Limited Oxidation; *J. C. Balsbaugh (M'35), A. B. Assaf. 30 cents.* Under limited oxidation copper and lead produce electrical instability with power factor nearly proportional to metal area. Copper may produce very high losses without significant change in color, indicating copper compound formed in the cuprous state. Also, paper generally has negligible effect on electrical characteristics; products responsible for loss are not adsorbed by paper. In continuous oxidation, paper readily adsorbs oxidation products of acids and water. Copper–oil ratios, important in operating performance of oil–paper cables, indicate relatively high values for certain limiting conditions difficult to reproduce in satisfactory test cell. Small percentage of aromatics generally gives more stable oil and may be also a function of copper–oil ratio and of the amount of available oxygen. Oils with different physical characteristics show wide differences in electrical characteristics;

straight hydrocarbons are somewhat the same as commercial insulating oils. It is believed that the type of hydrocarbon plays some part, though nonhydrocarbon components determine the characteristics to a large extent. Limited-oxidation characteristics of oils change on standing in container. Over-refined oils generally give electrical stability in initial period of continuous oxidation but finally produce large amounts of water and low-molecular-weight acids.

43-43—Skin Effect in Bimetallic Conductors; *B. R. Teare, Jr.* (*F'42*), *Josephine R. Webb* (*A'41*). *20 cents.* A knowledge of the behavior of bimetallic conductors at frequencies up to 150 kilocycles has become important for the designing of carrier-current communication systems. General equations are derived for bimetallic conductors with circular symmetry, giving the a-c distribution and the impedance per-unit length. The results are illustrated by applying them to a copper-covered steel conductor. Measurements of the a-c resistance in the same frequency range provide a check on the theoretical results. The studies made on the copper-covered steel conductor indicate that for all but the lowest frequencies its resistance is substantially that of the tubular copper portion alone and may be taken from the simpler formulas and curves already available for tubes.

43-50—Generation of Electric Charges by Moving Rubber-Tired Vehicles; *S. S. Mackeown* (*M'34*), *Victor Wouk* (*Enrolled Student*). *15 cents.* The current flowing to ground from an automobile whose rear wheels were turning on a dynamotor was measured. The magnitude of the constant current measured shows that the car is electrically charged by conduction through the tires. The experimental results are consistent with the conception of a simple equivalent electric circuit. Approximate values of the elements of this equivalent circuit were obtained. Constant current as high as four microamperes was measured from a car grounded through a meter when the two rear wheels were driven at a speed of 40 miles per hour on the dynamotor. These results were checked by road tests. Calculation shows that the tires are sufficiently conducting to discharge the car in a short time after the car is stopped.

Communication

43-14—An Electromechanical Calculator for Directional-Antenna Patterns; *Carl E. Smith* (*M'38*), *Edward L. Gove* (*M'35*). *15 cents.* An electromechanical calculator has been designed for the rapid solution of directional-antenna patterns. The machine automatically draws the field-intensity curves to any desired scale on polar coordinate paper and indicates the rms value for drawing a circle of the equivalent non-directional pattern. The fundamental design of the calculator does not limit the number of antennas. Not only is the horizontal directional field-intensity pattern, such as used in broadcast practice, readily available but the field-intensity curves at any elevation angle can be drawn with equal ease. The vertical-radiation characteristics of the several antennas can be selected at will. This makes it possible to explore the solid-contour surface of the whole hemisphere in a relatively short time and also to determine the total power radiated from the system. In addition, the calculator is useful for determining the solid-contour surface of parallel horizontal antenna systems.

43-58—Effect of Radio Frequencies of a Power System on Radio-Receiving Systems; *C. V. Aggers* (*A'39*), *W. E. Pakala* (*A'38*), *W. A. Stickel*. *15 cents.* This paper describes tests and gives results of radio-frequency measurements to determine the correlation between radio-frequency voltages and fields of power lines and the effects of these on the radio-listener's antenna. These results are useful in the approximate determination of the influence on radio-receiving systems of radio-frequency voltages sometimes produced incidental to the operation of a power system.

Domestic and Commercial Application

43-61—Rural Electrification Engineering and Electroagricultural Engineering; *M. M. Samuels* (*F'24*). *15 cents.* A survey is presented of developments in the fields of rural electrification and electroagricultural engineering since their beginnings. The paper discusses rural distribution lines, telephone co-ordination, voltage regulation, ground testing of rural circuits, electrical soil treatment, the problems of water supply and home lighting, electric equipment on the farms, and other similar subjects. Possible developments in these fields after the war and directions in which progress will be made are considered at some length.

Electrical Machinery

43-16—Mobile Capacitor Units for Emergency Loading of Transformers in Open Delta; *Herman B. Wolf* (*M'37*), *G. G. Mattison* (*A'41*). *15 cents.* Present conditions necessitate full-load operation of substation transformers; therefore, as the number of loaded substations increases, the problem of maintaining service upon the failure of one transformer in a delta-delta bank becomes more serious, for the supply of emergency replacement transformers is limited. Moreover, the time required to move and install replacement transformers results in a comparatively long curtailment of load or interruption to service. One solution to this problem utilizes mobile capacitor units with capacitance arranged for correcting the unbalance in voltage and current resulting from open delta operation and at the same time reducing the transformer loading to within the range of forced air cooling. The mobile unit may be towed by a car or light truck and is applicable to loads up to 1,200 kva or more, depending on the power factor, two or more mobile units being applied to larger loads. Simplicity of connection and high mobility permit rapid installation.

43-18—Equivalent Ambient Temperatures for Loading Transformers; *W. C. Sealey* (*M'38*). *15 cents.* Safe overloads for transformers can be determined by a modification of the American Standards Association rule for overloading, to permit the use of an equivalent ambient temperature which will result in the same loss of life as for continuous operation at 30 degrees centigrade ambient and full load. Based on relations governing aging of insulation, methods are developed for calculating the equivalent ambient temperature based on weather-bureau records. The equivalent ambient temperature for each month is calculated as the sum of the greatest recorded monthly mean temperature, plus a daily correction factor based on the greatest recorded daily range, plus a monthly correction factor based on the greatest recorded monthly range. Monthly equivalent ambient temperatures so obtained can be used in combination with load curves to determine the permissible safe load for a transformer for a given locality.

43-24—Substation-Transformer Emergency Overloading Practice; *L. W. Clark* (*M'25*). *20 cents.* The allowable emergency overload capacity of any transformer can be matched quickly and accurately with the overload to be carried taking full account of the individual transformer characteristics and the specific shape of the overload curve. The method of reaching a common basis for ready comparison consists of

1. Determining the allowable 24-hour steady load that can be carried on the transformer without exceeding certain agreed-upon limits.

2. Converting the specific load curve to a 24-hour steady load which would cause equivalent aging of the transformer insulation.

Nomographs are included for quick determination of allowable transformer 24-hour overloads, taking into account ambient temperature, top-oil rise, average copper rise, and ratio of copper to core loss. Empirical multipliers are also given which facilitate the conversion of the load curve to equivalent 24-hour steady load in no more time than it would take to calculate load factor.

43-31—Synchronous Motors With Controlled Excitation for Suddenly Applied Loads; *W. K. Boice* (*A'39*), *B. H. Caldwell* (*A'37*), *M. N. Halberg* (*A'29*). *25 cents.* This paper shows the advantages of automatic control of the field current of syn-

chronous motors applied to varying loads. These include higher operating efficiency and better power-system voltage regulation. Furthermore, for certain types of load, the use of automatic field control, properly coordinated with the motor design, will permit substantial saving of critical materials. The use of automatic field control is not limited to applications in which load changes occur gradually. The paper shows that in many cases such control is entirely practical even where high peak loads are suddenly applied. The method of analysis developed can be used to determine the performance of any synchronous motor with various excitation systems and load changes. Curves are included which show the maximum suddenly applied load that can be carried with a variety of motor and excitation system characteristics. The calculations are confirmed by load tests on a 2,100-horsepower motor.

43-36—The Rating of Power Transformers as Determined by the War Emergency; *R. J. Salsbury* (*M* '34), *A. F. Phillips* (*A* '32). *25 cents.* During the war it is desirable to base station ratings on the recurrent capacitance of all the transformer banks available for service rather than attempt to set up abnormally high emergency ratings based on the failure of one unit. If a maximum utilization of the total transformer capacitance is to be realized, it is essential that each transformer bank be calculated individually, since the thermal ratings of units of the same size vary widely. A method is discussed of systematically increasing transformer ratings as the station load grows, whereby the amount of detailed calculations and supervision of the loads are reduced to a minimum. Four steps are used in this method: the first step considers the ambient temperature; the second step, the manufacturer's test data and operating conditions; the third step, the thermal capacity, and the fourth step, the length of time at each hot-spot temperature. This last step, which is called the equal-life method of rating, takes into consideration the variations in daily peak loads, the variation in ambient temperatures, and the hot-spot temperature cycle. Each successive step which usually results in a higher rating utilizes the data obtained from the previous method. Several words of caution with respect to rating transformers are mentioned, and methods of handling emergencies are briefly discussed.

43-47—Factors Affecting the Design of D-C Magnets; *L. T. Rader* (*A* '34). *15 cents.* This paper outlines some of the factors which should be considered in the design of d-c magnets. The usual types of steel used are discussed briefly, including their influence of pole-face area on the force developed by the magnet. Flux measurements on a number of magnets show that theoretical calculations are often in great error because of factors such as leakage and saturation which are usually neglected. Data show that the flux in a d-c magnet with a small air gap may vary by as much as 300 per cent between one part of the circuit and another.

43-56—Cooling Power Transformers by Forced Circulation of Cooling Medium; *K. K. Paluev* (*M* '29), *L. H. Burnham* (*A* '07). *25 cents.* The paper discusses the various methods that have been used in cooling power transformers by forced circulation of the cooling medium, and points out the benefits:

1. To the war effort in the saving of critical materials.

2. To the user in first cost, shipment, installation station layout, and mobility.

The selection of proper control equipment is analyzed from the standpoint of protection and reliability of forced cooling. The relation between hot-spot and average winding temperatures and the future for forced cooling after the war are discussed.

43-62—Proposed Guide for the Selection of Electric Motors and Motor Controllers; *AIEE committee on electrical machinery and industrial power applications. 15 cents.* (Applies to American Standard C50, "Rotating Electrical Machinery," and AIEE Standard 15, "Industrial Control Apparatus.") The proposed guide explains briefly the necessity for conserving critical materials. It includes recommendations for selecting the size of electric motors, the type of electric motors, the size of motor controllers, and the type of motor controllers. Recommendations for selecting the size of electric motors include:

1. An accurate determination of the load requirements.

2. Factors to be used in determining the motor size on the basis of the load requirement and the type of motor required.

Recommendations for selecting the size of motor controller are based on the motor size with which it is to be used. Recommendations for selecting the type of motor and motor controller indicate simplifications which may be made in selection that result in savings of critical material. In the case of motors, the relative quantity of materials required for various types is indicated.

Industrial Power Applications

43-17—Paired-Phase Bus Bars for Large Polyphase Currents; *L. E. Fisher* (*M* '38), *R. L. Frank* (*A* '40). *15 cents.* The design of efficient conductors for large alternating currents has always been a problem, and the problem is especially difficult with large low-voltage, polyphase currents such as are found in enclosed bus-bar distribution systems for industrial plants. A new paired-phase method of arranging bus bars is described, which has excellent temperature rise, voltage drop, energy loss, and structural characteristics, for polyphase currents in the range of 1,000 amperes and above at 600 volts and less. The emphasis of the paper, however, is upon general characteristics of the paired-phase arrangement rather than the particular application to enclosed bus-bar systems. Comparative tests upon conventional laminated and interlaced arrangements and upon the paired-phase arrangement are presented, and the effect of varying dimensions is discussed. In addition to temperature-rise, voltage-drop, and energy-loss measurement, the current-density within the bus bars was studied by means of exploring wires, and the paired-phase arrangement is shown to be characterized by a peculiar current distribution which forms the basis for an explanation of its properties. A simple mathematical theory is developed to explain further the properties of the arrangement and to permit their calculation. Descriptive and performance data upon a variety of sizes of commercial paired-phase bus way are included.

43-40-ACO*—A Proposed Wartime Guide for Industrial-Power-Distribution Systems; *AIEE committee on industrial power applications. 70 cents.* The purposes of this proposed guide are to promote the use of sound engineering principles in the design and selection of industrial distribution systems and thereby conserve critical materials, and, in addition, to outline suggestions for the war period for the selection and application of apparatus and materials for use in these systems in order to promote further the saving of critical materials. The guide is divided into four sections. The first section will treat the broad subject of system planning. The second section deals with the problems involved in connection with the primary switching feeders of the usual industrial distribution systems. The third treats problems involved in connection with the transformation and low-voltage feeder protection. The fourth section covers the problems involved in the low-voltage distribution feeders, panelboards, bus distribution equipment, and load circuits. The guide applies to the following Standards: American Standards C57.1, C57.2, C57.3; AIEE Standard 19; American Standards C37.4, C37.5, C37.6, C37.7, C37.8, C37.9; AIEE Standards 20, 22, 23, 27, 27*A*, 28, 30, 33; AIEE reports 21, 25, 31.

43-41—The Power-Recovery System of Testing Aircraft Engines; *G. E. Cassidy* (*application pending*), *W. A. Masteller, W. L. Wright. 20 cents.* Aircraft engines must be tested and broken in by operation under load for considerable periods of time before they are shipped from an aircraft-engine manufacturing plant. Several techniques are in vogue for accomplishing this testing, none of which utilizes the power output of the engines in test except a recently adopted electrical system of testing that has come to be referred to as the power-recovery system of testing aircraft engines. The paper describes the development of this electrical system and the part which it is playing in the testing of the large aircraft engines being built today. Data obtained from engine plants operating under the

*ACO—Advance copies only available; not intended for publication in AIEE *Transactions*.

electrical system are included to illustrate the advantages of the electrical system over other systems of testing aircraft engines.

Instruments and Measurements

43-35—The Cathode-Ray Oscillograph Applied to Long-Time Switching Transients; *G. W. Dunlap* (*M '42*,) *N. Rohats* (*A '36*). *15 cents.* The cathode-ray oscillograph, because of its inherent characteristics, is ideally suited and extensively used for the measurement of transient voltages associated with switching operations. The type of oscillograph ordinarily used covers a wide range of measurement conditions and is necessarily large and expensive. For this reason very few such units are available, and new problems, arising from the necessity of providing reliable service with loads increasing because of the war effort, have required every available measurement facility. In two recent applications, where extremely wide-range performance was not required, a two-tube low-voltage cathode-ray oscillograph was used successfully. This oscillograph and the two applications are described, and it is shown how such measurements of long-time transients may be made with portable, inexpensive, and relatively simple equipment embodying the advantages of cathode-ray oscillography.

43-37—Measurements Pertaining to Co-ordination of Radio Reception With Power Apparatus and Systems; *C. M. Foust* (*M '31*), *C. W. Frick* (*A '19*). *30 cents.* An adequate and practical co-ordination between power circuits and radio receivers is necessary to the end that each may provide effective service in its own field. Progress in achieving this co-ordination has been realized as rapidly as pertinent measurements have become obtainable. What to measure and how to measure it has been the basic problem. This paper deals with several outstanding aspects of the co-ordination problem, particularly from the measurement point of view.

1. Radio-noise meter calibrations.
2. Relation of apparatus noise levels to radio-receiver interference.
3. Radio-influence voltage for apparatus.
4. Radio-influence voltage variables in apparatus testing.

Under these headings data and interpretations are presented showing the performance fidelity of available noise meters, a series of ratios through which apparatus-influence voltages can be related to radio-receiver noise, considered limits of radio-influence voltages for apparatus, recommended test voltages, and several factors critical to influence voltage levels in apparatus.

43-59—Insulation Testing of Electric Windings; *C. M. Foust* (*M '31*), *N. Rohats* (*A '36*). *15 cents.* A description is given of a new winding-insulation testing equipment and method designed to provide adequate turn-to-turn and conductor-to-ground test-voltage stresses. Thus the tester fulfills the essential requirements for adequate dielectric testing of equipment on the production line and gives a definite indication when any defect arises. The voltage applied is designed to represent, with suitable safety margins, the kind of voltage stresses prevailing in service. The new winding-insulation testing equipment is made up of a repeating-type surge generator, a synchronized cathode-ray oscillograph, and suitable motor-driven and manual switching equipment. The repeating-type surge generator provides a succession of testing voltage waves controllable in shape and adjustable to provide the necessary turn-to-turn and conductor-to-ground stresses. The cathode-ray oscillograph is automatically timed to give a stationary image of the wave. A novel switching equipment and oscillograph-deflection connection controls the application of the voltage surges and so indicates wave shapes that insulation imperfections or winding dissymmetries are definitely revealed.

Land Transportation

43-33—Keep Them Rolling; *J. W. Teker* (*A '31*). *20 cents.* Preventive maintenance methods applied to electric and Diesel-electric locomotives now so essential to wartime transportation will keep locomotives on the road, ease the burden on repair shops, and conserve time, material and labor. A review of the fundamentals underlying common maintenance functions, such as apply to the lubrication of sleeve bearings, antifriction bearings, and gearing; the distinction between cog wheels and gearing with its relation to motor life, and a consideration of the far-reaching effects of operational abuses from a basic viewpoint, should stimulate responsible engineers and operators to examine and test their methods in this light. There is much that can be done while the locomotives are over the service pit during layovers in detection of impending trouble and in applying corrective measures. Failures do not happen—they are caused, and the analysis of events leading to them is necessary before the efforts of available manpower and facilities can be directed, not only in making repairs but in the application of preventive measures.

43-49—Factors Involved in the Selection of Railroad Motive Power; *H. C. Wilcox, A. G. Oehler* (*F '26*). *20 cents.* The paper presents the position of the three types of motive power in railroad service and offers a brief historical background to show how each one arrived at its present status. A table lists advantages and disadvantages inherent in each type and includes supplementary information to explain the listings in the table. The subject is presented from the viewpoint of the user, and a method of determining more closely the place for each type of locomotive is suggested. An appendix lists all of the considerations which must be included in a complete cost study.

Power Transmission, Distribution

43-12—Impulse and 60-Cycle Characteristics of Driven Grounds, III—Effect of Lead in Ground Installation; *P. L. Bellaschi* (*F '40*), *R. E. Armington* (*A '42*). *20 cents.* This paper, the third of a series, presents the impulse characteristics of leads and grounds. Typical down-leads and tower structures in combination with common shallow and deep-driven grounds, parallel grounds, and counterpoise grounds are studied. The inductance, resistance, capacitance, mutual effects, and time constants of the leads and grounds are determined and their relative importance discussed. From this, the analysis and calculations are simplified. In like manner ground installations comprising multiple paths to earth are amenable to simplified treatment. The terminal conditions in the earth and their importance are also surveyed. Comparative results are presented in curves which give the voltages and their form in ground installations for currents corresponding to lightning conditions. The impulse voltages developed are compared to the insulation characteristics of the installation (station and line apparatus, or object protected) and the problem of grounds assessed in relation to the protection and co-ordination of insulation.

43-13—Steady-State and Transient-Stability Analysis of Series Capacitors in Long Transmission Lines; *J. W. Butler* (*M '38*), *J. E. Paul* (*A '39*), *T. W. Schroeder* (*A '37*). *15 cents.* This paper presents the results of an analysis made to determine basic performance data of compensated lines under steady-state and transient conditions. Such performance data are fundamentally necessary for a complete analysis to determine where reactance compensation is economically applicable. Certain general conclusions can be drawn immediately, based on the performance data and a consideration of present-day good operating practice. The studies reported were made with the aid of the network analyzer, steady-state power limits and transient data for a receiving-end stub-feeder fault being obtained for lines 150, 300, and 450 miles long. Transient power limits were found for two parallel 300-mile lines with a high-voltage sending-end fault resulting in the switching out of a line section as a function of sending-end generator and receiver system capacity. In addition to showing the effect of various degrees of reactance compensation and number of switching stations, all studies evaluate the effect of transmission voltage, generator inertia, transient reactance, and short-circuit ratio. Illustrations are given indicating how the data presented may be used to find the effect of various combinations of these factors, so they may be used to an economically optimum degree.

43-20—Intrasystem Transmission Losses; *E. E. George* (*F '35*). *30 cents.* This paper

describes a new method of calculating transmission losses within power systems. The method is based on the principle of superimposing the load distribution from each source, determining the current in each line as a sum of the individual load flows (with each in its proper direction), squaring this expression for current, and setting up an equation for losses in terms of megawatt generation at the various plants and of megawatt flows (in or out) at each interchange point. The procedure consists chiefly in deriving a special loss formula for a given power system. The formula is suitable for any condition of generation, load, and interchange. The loss formula may be used for determination of losses, either total or incremental; for billing, forecasting, or system planning purposes. It has been used by several power companies for hour-by-hour determination of incremental losses. Other companies have used the formula to derive a typical or average per cent loss, subject to review monthly, or less often if operating conditions are reasonably uniform. Results check well with a-c calculating-board studies and with longhand calculations of intrasystem losses.

43-21—Wood-Pole 230-Kv Transmission Lines; *O. S. Clark* (*M* '41). *15 cents.* This paper reports design conclusions reached and construction methods employed in the building of a 230-kv transmission line entirely of wood. Such construction has become necessary because of wartime restrictions on the use of steel. The design problem is not, fundamentally, a new one. Stresses involved, foundation requirements, and dimensions of structural members necessary to maintain separations between conductors and ground clearances present problems not encountered in the design of wood-pole transmission lines for lower voltages. In the interest of economy, braced crossarm members were used, which in turn made necessary complete transverse structural rigidity. The insulating value of wood was utilized in the design to obtain high impulse strength.

43-22—Ampere Load Limits for Copper in Overhead Lines; *A. H. Kidder* (*M* '39), *C. B. Woodward. 15 cents.* The paper deals with the carrying capacity of conductors in overhead lines, as determined by the effect of temperature and time upon the physical characteristics of the conductor. The paper does not deal with considerations of voltage variation, power loss, nor other factors that may favor larger conductors than are adequate physically for the immediate purpose. The paper presents a method for determining approximately the maximum continuous current-carrying capacity of conductors in overhead lines, as fixed by certain operating limits of temperature and time, beyond which it is expected that the physical characteristics of copper conductors might be materially impaired. The paper deals illustratively with conditions in the Philadelphia area, but the method is equally adaptable to any situation. The design limits of ampere ratings are from 10 to 35 per cent higher for bare conductors and from 10 to 20 per cent higher for covered conductors, than those previously used in the Philadelphia area. Operation at load equal to the design limit will, during 99.93 per cent of the hours in the average year, maintain copper temperatures below 100 degrees centigrade in normal operations and below 135 degrees centigrade in emergency operations.

43-25—Kilowatts, Kilovars, and System Investments; *J. W. Butler* (*M* '38). *15 cents.* What portion of the total system investment can one equitably allocate to the system kilovar requirements? A rational answer is given to this question, and it is shown that the kilovar requirements of a system in general should be divorced from the kilowatt requirements and that the two factors should be dealt with as independent commodities, if maximum usage of system capacity is to be made in producing kilowatts. It is shown that a value of two to six per cent of the system investment is chargeable to the kilovar requirement when it is supplied near the load by auxiliary kilovar generators, as contrasted to 20 to 25 per cent when supplied by kilowatt generators in the power stations, for systems operating around 80 per cent power factor. The possible effects of establishing rates for kilovars based on the cost of supplying them by kilowatt generators are discussed. It is shown that this procedure, in providing an excessive inducement for the consumer to generate his own kilovars, results in the important system design and operating factor of kvar control tending to pass out of the hands of the operating company into the hands of the consumer.

43-30—Pulling Loads on Single- and Multiple-Conductor Impregnated-Paper Lead-Encased Cable Solid Type; *A. P. S. Bellis* (*A* '25). *30 cents.* The pulling of lead-encased cable in underground systems by means of pulling grips or the like is an old art. Engineering consideration of the problem has failed to develop simple adequate rules for field use because of a lack of factual information as to what might be expected of the cable. It has been considered generally that no harm to the cable has resulted if visual evidence is not apparent on the outside of the sheath. The results of the investigation reported show evidence of disturbance of the mechanical uniformity of the insulation that is not detectable from an examination of the lead sheath. Certain factors in the problem have been evaluated, a field formula is offered, and a method of judging the possibility of damage to the cable through stretching the cable sheath excessively is suggested. It is hoped this work will stimulate renewed effort toward reduction of joint and cable failures within and adjacent to manholes.

43-26—Harmonics and Load Balance of Multiphase Rectifiers—Considerations in the Selection of the Number of Rectifier Phases; *R. D. Evans* (*F* '40). *15 cents.* This paper analyzes the operating characteristics of multiphase power rectifiers from the standpoint of harmonics, load balance and their interrelation, and their effects on the apparatus and circuits to which they may be connected. These factors are considered in connection with selection of the number of rectifier phases, which varies from six (four for very small sizes) to combinations of six-phase units to form a much larger number, such as 36, 72, or even 108 phases. More specifically, the problems of harmonics, load balance, and number of phases are considered from the standpoint of the effects on

1. Apparatus, particularly turbine generators and capacitors.
2. The wave-shape distortion on circuits that may be important in inductive co-ordination.
3. The possibility of resonance being encountered in the supply system to amplify one or more of the rectifier harmonics.

These problems have increased greatly because of the great number and large size of rectifier installations made in connection with the war.

43-34—Metering Power on the Low-Voltage Side; *A. J. Petzinger* (*A* '36), *B. E. Lenehan* (*A* '24). *20 cents.* Consumers of energy are often supplied from the high-voltage distribution or subtransmission circuits through stepdown transformer banks. When the consumers are to be charged on the basis of primary or high-voltage energy supply, some way is desirable of including the transformer losses, without necessitating the expense and difficulty of metering directly on the primary side. This paper presents a résumé of the various methods which may be considered. These methods may be classified broadly in four general groups. There is no "best method" for all installations, but each installation must be considered individually, including such factors as expense, customer relations, public-service commission requirements, and size of installation.

43-29—Transmission-Line and System Problems in Supplying Large Electric-Arc Furnaces During Wartime; *B. M. Jones* (*F* '42). *20 cents.* Transmission extensions are made for large electric furnaces, using the minimum of copper, and are designed to prevent an adverse effect on the system, particularly the lighting. Voltage flicker limits are made more liberal, and in many cases rampant furnace operation is permitted. The ten cases cited cover 20 electric-arc furnace installations varying in size from 1,500 kva to 15,000 kva in ten plants. Radical changes are developed by rearranging the transmission network, splitting it apart at various locations, isolating existing lines for exclusive furnace use, and adding extensions to these exclusive lines and to the network itself. A considerable amount of copper is saved—in one instance, 53,000 pounds are saved by reducing the requirements from 64,000 to 11,000 pounds, and in another instance no line copper at all is used, because of rearranging the consumer's high-voltage bus to isolate an exclusive line for the furnace.

43-45—Open-Delta Transformer Bank—Analysis of Circuit; *J. E. Clem* (*F'38*). *20 cents.* In this paper it is shown that induction motors operated from an open-delta transformer bank may have additional losses when operating at full load, ranging from 33 to 93 per cent of the full load losses. Under some conditions this may result in serious overheating. A new method of determining the regulation of an open-delta transformer bank is offered, in which the negative-sequence current, as well as the positive-sequence current, is considered. This new method gives correct results and may be applied whether the load in the secondary circuit is balanced or unbalanced. Also there is given a new formula for the calculation of regulation by means of which the results may be obtained to any degree of precision justified by the supporting data. Charts are supplied by means of which the correct amount of capacitance to be added to balance the secondary voltages on open-delta operation may be estimated, and an illustrated example is worked out. An example illustrating the application of the new formulas for regulation is included. In addition, a chart is given outlining a new simplified method of determining the line-to-neutral voltages from the unbalanced line-to-line voltages. Also there is included in the chart a new and more direct method of finding the positive- and negative-sequence components.

43-48—Shunt Capacitors; *general systems subcommittee of the AIEE committee on power transmission and distribution. 30 cents.* The Institute is at present fostering a program for encouraging discussion of means for obtaining greater loading out of existing equipment. As part of this program the general systems subcommittee of the power transmission and distribution committee has undertaken the task of analyzing what can be done with generators of reactive power in reducing the kva demand upon system elements, thereby releasing more of the system capacity for useful kilowatt loading. While this report is concerned primarily with the use of capacitors as generators of kilovars, many of the conclusions drawn herein can be applied equally to other generators of kilovars, such as overexcited synchronous machines.

Protective Devices

43-15—A New Generator Differential Relay; *A. J. McConnell* (*A'36*). *15 cents.* A new differential-relay principle, product restraint, is discussed specifically as applied to a generator differential relay. Restraining in response to the product of the incoming and outgoing currents rather than to their sum, the so-called restraining windings produce, during an internal fault, either

1. An operating force, if there is an external source of power.
2. No force at all, if there is no external source.

Consequently, there is no danger of failure to operate during an internal fault even if the differential (operating) circuit is sharply saturated. During a through fault, sharp saturation of the differential circuit provides, as the current level increases, a proportionately rapid increase in the slope characteristic, thereby causing the relay to be insensitive to the false differential current which may appear at the higher current levels because of d-c saturation of the current transformer. A relay incorporating the product-restraint principle is described.

43-19—Switching Overvoltage Hazard Eliminated in High-Voltage Oil Circuit Breakers; *Lloyd F. Hunt* (*F'38*), *E. W. Boehne* (*M'37*), *H. A. Peterson* (*M'41*). *15 cents.* In this paper a specific problem of high transient switching voltages on the 220-kv lines of the Southern California Edison Company, Ltd., is discussed. After the symptoms were diagnosed from a theoretical standpoint, a complete analysis was made, using the transient analyzer to determine the possible magnitudes of switching overvoltages under various possible system-operating conditions. Different means of subduing these over voltages were carefully considered, in the light of experience in related fields, and it was concluded that equipping the circuit breakers with internal resistors of the proper ohmic value afforded the best solution. The effectiveness of the method described in controlling the switching overvoltage hazard is significant, not only from the circuit-breaker standpoint, but from the arrester, relaying, and over-all system-operating standpoint as well, since lines and terminal equipment are freed from the possibility of being subjected to destructive switching overvoltages, regardless of the method of system neutral grounding.

43-27—Pilot-Wire Circuits for Protective Relaying—Experience and Practice; *relay subcommittee of the AIEE committee on protective devices. 15 cents.* Because of the increasing use of pilot-wire relays, and particularly for longer lines, the relay subcommittee initiated an investigation of the operating experience with the pilot channel itself. From this investigation it was hoped to determine the requirements for a reliable pilot channel. Unfortunately, the information obtained to date is not conclusive, and under war conditions the completion of this investigation appears to be unavoidably delayed. On the other hand, plant expansion necessary to the war effort has frequently called for quick decisions on relay schemes, and pilot wires have been used in many cases. Because the pilot-wire channel is the least known item in the pilot-wire relay scheme, the committee is publishing in this report the information now available to indicate the trend, so that prospective users of pilot-wire relaying may have the benefit of this preliminary work.

43-28—The Effect of Current-Transformer Residual Magnetism on Balanced Current or Differential Relays; *H. T. Seeley* (*A'27*). *20 cents.* High-speed current-balance relaying has been subject to occasional false tripping that has not been explained satisfactorily. Field and factory tests now show that this probably is due to differences in residual fluxes in the current-transformer cores. The limiting value of these fluxes can be calculated approximately, and they can be measured with portable instruments connected to the secondary winding. They may cause a deficiency in secondary current, especially during the first half-cycle of fault current, which will cause current-balance or differential-over current relays to operate falsely. This false operation can be avoided by the addition of a short inherent or external time delay with relays having a high dropout, or by the use of special current transformers.

32-32—An Improved Axial Air-Blast Interrupter for Severe Operating Duty; *P. L. Taylor* (*A'27*), *H. W. Martin* (*A'40*). *30 cents.* The development of an improved axial air-blast interrupter, whose performance permits long contact life at high currents, is reported. The evolution of the new interrupter is described and illustrated. Difficulties experienced during tests on successive arrangements of the device during its evolution are mentioned, and the means by which such difficulties were overcome are explained. A description of the 150,000-kva 5-kv vertical-lift breaker, incorporating the new interrupter, is included, and performance test data are submitted. The test data show the device to be capable of interrupting the lowest- to the highest-rated interrupting currents with a maximum arcing time of one current loop. Based on the test evidence submitted, the conclusion is reached that the device may be expected to require very infrequent contact replacement or maintenance and that it is capable of meeting the requirements of the most exacting applications.

43-37—Performance Requirements for Relays on Unusually Long Transmission Lines; *F. C. Poage* (*M'38*), *C. A. Streifus* (*A'36*), *D. M. MacGregor* (*A'37*), *E. E. George* (*F'36*). *30 cents.* This paper re-examines the fundamental principles of transmission-line relaying in view of the requirements of a 270-mile 154-kv interconnection between two systems. Of the possible bases—current, phase-angle, impedance, and impedance angle—the combination of impedance magnitude Z and impedance angle $\psi = \tan^{-1} X/R$ is chosen as most promising. Impedance circle diagrams for the interconnection are developed and plotted on resistance-reactance coordinates. By means of these diagrams there is charted the dynamic behavior of the systems during faults and surges of synchronizing power. The desirable areas of "trip" and "no-trip" are mapped, and general specifications for the performance of relay systems are presented in terms of impedance magnitude and angle $Z<\psi$. This permits taking full advantage of all the possible synchronizing power inherently available over the interconnection and at the same time permits relays properly to recognize faults and the approach of out-

of-step condition. The principles developed are applicable to circuits of any length over which it is possible to maintain synchronism between constant voltage systems. This is one of a group of three related papers. Papers 43-38 and 43-39 cover design of relays in accordance with these principles and staged-fault tests on the completed interconnection.

43-38—Protective Relaying for Long Transmission Lines; *A. R. Van C. Warrington* (*A '31*). *20 cents.* Some of the new system interconnections necessitated by war needs have had to be unusually long. Conventional distance and carrier relays are not applicable to very long lines, because the impedance they measure under load or power-swing conditions may be low enough to make them trip wrongly. The paper describes a new method of relaying which uses phase angle to distinguish between normal and abnormal conditions which present similar impedance to the relays. The new method has the advantages that

(*a*). Tripping an out-of-step conditions is provided and blocking on power-swing conditions.

(*b*). The degree of system separation that is desired for tripping can be set accurately.

(*c*). No time is required to recognize out-of-step conditions.

The protective relays are associated with an unusually flexible arrangement for controlling manual and automatic reclosing, both instantaneously and by voltage and synchronism check. Reactors are cut in automatically to prevent overvoltage on single-end feed.

43-39—Staged-Fault Tests of Relaying and Stability on Kansas-Nebraska 270-Mile 154-Kv Interconnection; *C. W. Minard, R. B. Gow* (*A '35*), *W. A. Wolfe* (*M '36*), *E. A. Swanson. 30 cents.* This paper presents results and conclusions from 22 staged-fault tests made on a 154-kv transmission line and the terminal systems to check the characteristics and performance of newly developed long-line relays which were designed to discriminate between faults and high power swings. Observed power swings and relay performance are compared with predictions made on basis of network-calculator studies and design of relays. Also presented are data on the transient-stability limit of the interconnection, observations made during the tests, measured values of line constants, and results of carrier-current attenuation tests. Description is given concerning manner of initiating the faults, scheduling the power flows, and organization of personnel for the tests.

43-44—A New 50,000-Kva-5 Kv Oilless Circuit Breaker and Metal-Clad Switchgear Unit; *R. C. Dickinson* (*M '41*), *B. I. Hayford* (*A '23*). *15 cents.* Progress in the development of the larger air-interrupting devices, careful cost analysis, and improved manufacturing methods have made it possible to produce economically a 50,000-kva interrupting-capacity unit comparable in space requirements and height with the corresponding oil circuit breaker. A metal-clad switchgear unit has been designed to utilize the new air circuit breaker, and the performance of the complete unit is demonstrated by high-power laboratory tests.

43-51—A Vertical-Flow Compressed-Air Circuit Breaker and Its Application on a 132-Kv Power System; *H. A. P. Langstaff* (*M '27*), *B. P. Baker* (*M '41*). *15 cents.* The compressed-air circuit breaker for indoor powerhouse service is becoming very popular. However, its use for high-voltage outdoor service is still in the field-trial stage. Several high-voltage porcelain-clad circuit breakers of American design are now in service, and their performance is being carefully watched. A 138-kv 1,500,000-kva three-pole breaker has been installed at the Kittanning substation of the West Penn Power Company. Before installation, its interrupting ability was checked to 5,900 amperes with full 132 kv on a single-pole unit and on a circuit with a transient-recovery rate of 3,100 volts per microsecond. The mechanical operation was tested with the breaker in a heavily iced condition at −14 degrees Fahrenheit. The air supply system was tested at −4 degrees Fahrenheit. Both were found to operate satisfactorily. The breaker was installed on the most active line of the West Penn Power system. Since then it has had 41 operations, five of which were on faults. Its operation to date has been satisfactory in every detail, and it is hoped that this new device will meet operating requirements and materially reduce the time outage for servicing such apparatus.

43-52—The Autoblast Interrupter Switch; *E. A. Williams, Jr.* (*M '42*), *W. G. Harlow* (*A '42*). *20 cents.* An air interrupter switch may be defined as a non-automatic air switch which combines the functions of a disconnecting switch with the ability to interrupt current up to a predetermined magnitude. It differs primarily in function from a circuit breaker in that it cannot interrupt overload or short-circuit currents. General specifications for interrupter switches are proposed. The autoblast interrupter switch is an air interrupter switch having each pole equipped with an arc chute into which the arc is driven by a blast of air generated automatically when the switch is opened. Interruption occurs within the chute by elongating and cooling the arc. The construction and operation of this switch is described, and test data are presented to show compliance with the proposed general specifications.

43-53—A Multiorifice Interrupter for High-Voltage Oil Circuit Breakers; *L. R. Ludwig* (*M '41*), *W. M. Leeds* (*M '38*). *25 cents.* Present-day requirements relating to the manufacture and operation of high-voltage oil circuit breakers demand the least use of critical materials and the minimum time out of service for inspection and maintenance. While multibreak designs for high-speed three-cycle breakers have shown satisfactory performance, a comparison between such contacts and the simpler structures used in conventional two-break assemblies for eight-cycle operation suggests the desirability of reversing the trend toward a large number of breaks. By making use of newly developed and highly effective multiorifice oil-flow interrupting units, it appears practical to build even the highest-speed breakers with but two interrupting units per pole. High-power laboratory tests on low magnetizing and charging currents, as well as short-circuit currents corresponding to interrupting ratings of 2,500,000 kva and above, have demonstrated the exceptional arc-extinguishing effectiveness and low arc-energy dissipation of the multiorifice interrupter in high-speed oil circuit breakers.

43-54—Oil-Impregnated-Paper High-Voltage Capacitor Bushings for Circuit Breakers and Transformers; *H. J. Lingal* (*M '41*), *H. L. Cole* (*M '21*), *T. R. Watts* (*M '34*). *25 cents.* Oil-impregnated-paper high-voltage capacitor bushings are made in ratings 92 to 230 kv, with capacitors wound from uncoated paper. The bushings have both ends encased in porcelain to retain permanently the superior electrical characteristics obtained by combining the advantages of capacitor-type construction with those of oil-impregnated-paper insulation. Complete interchangeability of bushings is obtained for transformers and circuit breakers of current design. They may also be used interchangeably with most bushings of older design. The construction and treating is described, and a discussion of electrical and mechanical tests is included.

43-55-ACO*—Preliminary Report on Guides for Application and Operation of Circuit Breakers and Switchgear; *AIEE subcommittee on circuit breakers, switches, and fuses. 15 cents.* The present war emergency makes it necessary that maximum use be made of existing equipment and that a minimum amount of critical materials be used for new equipment. To this end guides have been prepared as an aid to those involved in the application and operation of circuit breakers and switchgear. The maximum utilization of existing switching equipment may be realized if the following procedures are adopted:

1. Provision of means for increasing current-carrying capacity.

2. Provision of means for increasing interrupting capacity of circuit breakers.

3. Institution of maintenance practices to minimize failures and resulting destruction of critical materials.

These guides are intended to cover equipment of the following types:

1. A-c power circuit breakers above 600 volts both indoor and outdoor (American Standards C37.4 to C37.9 inclusive).

2. Air disconnecting switches (AIEE Standard 22).

3. Switchgear assemblies (AIEE Standard 27).

4. Current-limiting reactors (American Standards C57.1 to C57.3 inclusive).

The present recommendations include reactors, as this type of equipment is

*ACO—Advance copies only available; not intended for publication in AIEE *Transactions*.

intimately associated with circuit breakers and switchgear and is frequently installed in switching structures.

43-63—Application of Lightning-Protective Devices in Wartime; *I. W. Gross (M '40). 15 cents.* The application of protective devices is reviewed in the light of possible savings in critical materials and man hours. It is pointed out that the indirect savings resulting from a careful selection and application of arresters may amount to far more than elimination or reduction in materials used in the arresters themselves. Among the considerations presented and discussed are:

1. Applying arresters on the basis of 60-cycle rating.
2. Use of line-type in place of station-type arresters.
3. Protection of equipment not already protected.
4. Rebuilding or revamping existing arresters.
5. Use of protective devices other than the conventional lightning arrester.
6. Reduction in length of arrester leads.
7. Location of the arrester close to the equipment to be protected.
8. Testing arresters.

SECTION • • • • •

Washington Section Holds Joint Meeting With ASCE and ASME

Material conservation and production problems in the war effort was the theme of a joint meeting of the Washington Section of the AIEE with the American Society of Civil Engineers and the American Society of Mechanical Engineers on Wednesday evening, December 9, 1942, at the Department of Commerce Auditorium, Washington, D. C. Brigadier General W. H. Harrison (F '31) AIEE past president, vice-president on leave from the American Telephone and Telegraph Company, New York, N. Y., now serving as director of procurement, headquarters, Services of Supply, United States Army, addressed the gathering of about 700 persons. Pointing out instances of Army sacrifices of critical material in one branch to provide it for other more important manufacture, he stated, "In the effort to accelerate the program of conservation we are trying to avail ourselves of every particle of information obtainable from our allies and our enemies."

PERSONAL • • • •

H. H. Wagner (A '29, M '37) electrical engineer, Pennsylvania Transformer Company, Pittsburgh, Pa., has recently been appointed chief electrical engineer. He first joined the company in 1932 as design and development engineer in charge of the design of power and distribution transformers, later becoming electrical engineer. He received the degrees of bachelor of arts (1925) from Culver-Stockton College, bachelor of science in electrical engineering (1927) from the University of Illinois, and master of science in electrical engineering (1933) from the University of Pittsburgh. From 1927 to 1928 he was enrolled in the graduate student course of Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and from 1928 to 1930 he was employed in the power transformer department as electrical design engineer at the Westinghouse company in Sharon, Pa. Prior to his affiliation with the Pennsylvania Transformer Company in 1932 he was with the Pittsburgh transformer works, Allis-Chalmers Manufacturing Company (1930–32) as electrical design engineer in charge of the technical data department. **H. D. Salton** (A '37, M '41) development engineer, Pennsylvania Transformer Company, Pittsburgh, has been appointed chief design engineer. He was graduated from the Technical University of Darmstadt, Germany, in 1923 with a degree in electrical engineering. In 1924 he entered the employ of the German General Electric Company, Berlin, as designing engineer in the transformer department. He continued his association with that company until 1933, ultimately becoming division manager. In that year he became a consulting engineer engaged in transformer design. In 1936 he came to the United States and joined the Pennsylvania Transformer Company as development and research engineer. He has been with the company continuously since that time.

A. C. Farmer (A '35) assistant manager, transformer sales department, Sharon, Pa., has been named assistant to the vice-president. He received the degree of bachelor of science in electrical engineering in 1908 from the University of London, England, and in 1909 joined the Westinghouse company in the student course at East Pittsburgh, Pa. From 1910 to 1918 he served in the transformer section, and was appointed manager of the distribution transformer section of the supply department in the latter year. He became manager of distribution apparatus sales at headquarters in East Pittsburgh, Pa., and was named assistant sales manager at Sharon, Pa., in 1932. **R. L. Whitney** (A '21, M '28) sales manager, porcelain department, Westinghouse Electric and Manufacturing Company, Derry, Pa., has been appointed sales manager of the company's transformer division, Sharon, Pa. He was graduated from the University of Colorado in 1920 with the degree of bachelor of science in electrical engineering and immediately joined the Westinghouse company in the power sales department, East Pittsburgh, Pa. He was subsequently transferred to the sales office in Philadelphia, Pa., and later, to the sales office in Allentown, Pa., where he became sales manager in 1931. He was transferred to the porcelain department, Derry, Pa., in 1936, in the same capacity. **A. P. Bender** (A '18) former sales manager, transformer division, Sharon Pa., has been made assistant sales manager "to afford the best possible opportunity for his complete recovery" from an extended illness. He has been with the company since 1906.

G. M. Stevens (A '22) assistant manager, River Works, General Electric Company, Lynn, Mass., recently has been appointed acting manager. He has been with that company since 1899, when he entered the four-year apprentice course at the River Works. From 1904 to 1912 he was employed as executive on various lines of motor manufacturing, joining the gear and motor department in the latter year. In 1916 he was sent to Russia to assist in the installation of electrical apparatus. Upon his return to the United States in 1917 he was named superintendent of the company's plant at Taunton, Mass., and in 1925 was transferred to the River Works as general manufacturing superintendent. He became general superintendent there in 1929, and was appointed assistant manager in 1940. **N. M. DuChemin** (A '29) assistant manager, West Lynn Works, Lynn, Mass., has been appointed acting manager. He first became associated with the General Electric Company in 1914 as apprentice machinist at the River Works. He served during the World War I as ensign in the United States Navy, and upon his return to the General Electric Company in 1919, was assigned to the turbine department at the River Works. In 1923 he became general superintendent of the West Lynn Works, and in 1935 he was appointed assistant manager.

R. H. Tapscott (A '18, F '29) president, Consolidated Edison Company of New York (N. Y.), Inc., has been named that company's chief executive officer. He was born in Brooklyn, N. Y., on August 31, 1885, and was graduated from Union College in 1909 with the degree of bachelor of science in electrical engineering. He immediately joined General Electric Company, Schenectady, N. Y., in the testing department, and from 1910 to 1917 he served in the lighting engineering department. In 1917 he became assistant electrical engineer, New York (N. Y.) Edison Company. He served in this capacity until 1924, when he was appointed electrical engineer. In 1932 he became vice-president of that company and of the United Electric Light and Power Company, New York, N. Y. He became a director of both companies in 1935. In 1936 he was elected vice-president of the Consolidated Edison Company of New York when the New York Edison Company, Inc., was merged with the Consolidated Edison Company. He has served as president and trustee of the Consolidated Edison company since 1937. He is a past vice-president (1934–36) and a past director (1930–34) of the Institute.

C. F. Wagner (A '20, F '40) manager of central-station engineering, and **Dean Harvey** (A '04, M '13) materials and standards engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., have been awarded the Westinghouse Order of Merit for outstanding contributions to the electrical industry. Mr. Wagner was honored for his studies in lightning and for his practical application of mathematics to power system analysis

machine characteristics, and short circuit calculation. He joined the Westinghouse company in 1918 in the research division, and was transferred to the engineering division in 1924, where he was concerned with power transmission developments. Mr. Harvey was cited for his contribution to the war effort as a member of the conservation division of the War Production Board and for pioneering work in the development of materials and process specifications both within the company and for national organizations. He joined the Westinghouse company in 1904 as a design engineer on detail apparatus, insulation, and switchboards. Since 1911 he has prepared specifications for materials and methods of testing at the East Pittsburgh works.

W. A. Schumacher (M '27) outside plant engineer, plant and engineering department, Postal Telegraph-Cable Company, New York, N. Y., has recently been appointed superintendent of plant. He received the degree of bachelor of science in electrical engineering in 1917 from the University of Nebraska. From 1917 until 1920 he was variously associated with Northwestern Telephone Exchange Company in their St. Paul, Minneapolis, and Virginia, Minn., offices. In the latter year he was appointed wire chief at Fargo, N. Dak., for the Northwestern Bell Telephone Company, and in 1922 he was transferred to Omaha, Nebr., to become assistant to the construction engineer. He became engineer in charge of provisional estimates and outside plant engineering practices later in the same year, construction engineer and engineer of outside plant engineering practices in 1923, and division plant engineer in 1926. He entered the employ of Postal Telegraph-Cable Company in 1929, where he has been serving continuously since as plant engineer.

H. S. Osborne (A '10, F '21) plant engineer, operation and engineering department, American Telephone and Telegraph Company, New York, N. Y., has recently been made assistant chief engineer of that department. He received the degrees of bachelor of science in electrical engineering (1908) and doctor of engineering (1910) from Massachusetts Institute of Technology. He entered the engineering department of the American Telephone and Telegraph Company in 1910, and became assistant to the transmission and protection engineer in 1914. In 1920 he was appointed transmission engineer, and in 1939 he became operating results engineer in the operation and engineering department. He was appointed plant engineer in 1940. Doctor Osborne is a past director of the Institute and is currently serving as AIEE president (*EE, Mar. '42, p. 162*).

C. K. Strobel (A '24, M '30) research physicist, research department, Robertshaw Thermostat Company, Pittsburgh, Pa., has been appointed assistant director of the research laboratory. He received the degrees of bachelor of science in electrical engineering in 1921 from Carnegie Institute of Technology, and master of science in physics from the University of Pittsburgh in 1933. He has been associated with the Robertshaw company since 1940, and prior to that time had conducted both individual and group research with Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in the research department of Union Switch and Signal Company, Swissvale, Pa., and in the development laboratory of Western Electric Company, New York, N. Y.

K. L. Hansen (A '17, F '34) consulting engineer, Harnischfeger Corporation, Milwaukee, Wis., has been elected president of the American Welding Society for 1942–43. He is a past vice-president of this organization, and a past vice-president of the American Institute of Electrical Engineers, representing the Great Lakes District (5) 1940–42.

R. T. Henry (A '24, F '33) assistant chief electrical engineer, engineering department, Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., has been appointed chairman of the electrical equipment committee of the Edison Electric Institute for 1942–43.

OBITUARY ••••

Axel Ames (A '09) sales engineer and engineering executive, power cable department, the Kerite Insulated Wire and Cable Company, Inc., New York, N. Y., died on November 23, 1942. He was born in Wakefield, Mass., on January 3, 1873, and received the degree of bachelor of science in civil engineering in 1895 from Massachusetts Institute of Technology. He immediately joined the Boston and Maine Railroad Company, serving as assistant engineer until 1896, and as track laborer and sub-foreman until 1898. During the Spanish-American War he served as captain in the United States Volunteer Engineers Corps, accompanying an expedition to Puerto Rico in 1899. In 1899 he became associated with the New York Central and Hudson River Railroad as assistant roadmaster, becoming supervisor of track later in the same year. From 1901 to 1904 he was associated with the Boston and Albany Railroad, first as roadmaster (1901–02) and later as signal and electrical engineer (1902–04). Following brief associations as signal engineer with the Lake Shore and Michigan Southern Railway (1904–06) and with the New York Central and Hudson River Railroad (1906–08), he joined the Kerite Insulated Wire and Cable Company, Inc., New York, N. Y., serving until his death. During World War I he served as a major in the United States Army Coast Artillery, and was retired in 1939 as colonel of the United States Army Coast Artillery Officers Reserve Corps. Colonel Ames also served as a member of the block signal and train control board of the Interstate Commerce Commission from 1907 to 1912.

Charles N. Ruess (A '25) superintendent of general shops, general plant division, Department of Water and Power, City of Los Angeles, Calif., died on September 7, 1942. He was born August 9, 1882, in Downers Grove, Ill., and entered upon his first association with the electrical industry in 1900 with the Western Electric Company, Chicago, Ill. He interrupted his association with this company in 1904 to become electrician and repairman, first with United Verdie Copper Company, Tucson, Ariz. (1904–05), and later with Calumet and Arizona Copper Company, Bisbee (1905–06). In 1906 he returned to the Western Electric Company, Chicago, Ill., serving in general assembly and installation work and as traveling repairman until 1909. In that year he joined the Department of Water and Power, City of Los Angeles, Calif., as superintendent of electrical maintenance at the Monolith cement plant on the Los Angeles Aqueduct project. In 1910 he was placed in charge of the aqueduct electric salvage section, and from 1915 to 1916 he was loaned to the County of Los Angeles as chief electrician and general foreman of the Monolith (Calif.) Cement Plant. In 1917 he was recalled by the city of Los Angeles to supervise the electrical repair shop in the newly organized Bureau of Power and Light and remained in this capacity until 1934, when he was appointed superintendent of general shops.

Charles E. Carpenter (A' 96) owner, Carpenter Laboratories, Hopewell Junction, N. Y., died on November 9, 1942. He was born on April 1, 1864, at Big Flats, New York, and attended Cornell University and the University of Minnesota. In 1890 he invented an enamel rheostat for controlling electric motors and generators, and established a new company, the Carpenter Enamel Rheostat Company, New York, N. Y., of which he became vice-president. In 1895 he joined the Ward Leonard Electric Company, Mount Vernon, N. Y., as vice-president, and during his association with this company he was awarded a gold medal at the 1898 Paris Exposition for his inventions. He formed the Carpenter Enclosed Rheostat Company in 1900, and in 1903 he joined the Cutler-Hammer Manufacturing Company of Milwaukee, Wis., in their New York office. He continued his affiliation as engineer in the mechanical and electrical engineering department of this company until his retirement in 1929. In 1930 he established the Carpenter Laboratories on his estate at Hopewell Junction, which he maintained until his death. He was the holder of numerous patents, among them an automatic device for controlling flat-bed printing presses, and a hydraulic governor which is used extensively to control large alternating current motors on high speed rotary presses.

Ralph B. Ward (A '24, M '26) retired chief of the electrical bureau, Newark (N. J.) Department of Public Safety, died July 26, 1942. He was born on January 25, 1882, in Newark, N. J., and began his engineering career in 1904, supervising the design and construction of switchboards for HOS Engineering Company, Newark, N. J. In 1907 he joined the Davis Electric Company, Newark, N. J., as foreman electrician, becoming superintendent of the designing and laying out of electrical installations in 1909. He became assistant electrical inspector in 1914 for Newark (N. J.) Department of Public Safety and from 1918 until his retirement in 1941 he served as chief electrical inspector and executive of the electrical bureau there.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on December 17, 1942, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Bryant, J. M., professor of electrical engineering, University of Minnesota, Minneapolis, Minn.

Henline, H. H., national secretary, AIEE, New York, N. Y.

Johnson, P. L., acting chief engineer, Southern California Telephone Company, Los Angeles, Calif.

3 to grade of Fellow

To Grade of Member

Carey, F. K., district engineer, Westinghouse Electric Elevator Company, Los Angeles, California

Dwonoczyk, V. L., electrical engineer, American Gas and Electric Service Corporation, New York, N. Y.

Eck, R. N., assistant supervising engineer, Cutler-Hammer, Inc., Milwaukee, Wis.

Grow, L. M., division superintendent, Southwestern Public Service Company, Plainview, Tex.

Howse, S. E., engineering supervisor, Technicolor Motion Picture Corporation, Hollywood, Calif.

Kieb, N. A., electrical engineer, Albert Kahn, Inc., Detroit, Mich.

Love, G. A., manager, electrical engineering department, Robert and Co., Jacksonville, Fla.

Prescott, H. L., development engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Rystedt, T., engineer, Western Union Telegraph Company, New York, N. Y.

Sohon, Harry, assistant professor of electrical engineering, University of Connecticut, Storrs.

Stark, Guy F., Owner, Stark Electric Co., Baltimore, Md.

11 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before January 31, 1943, or March 31, 1943, if the applicant resides outside of the United States or Canada.

United States and Canada

1. NORTH EASTERN

Alexander, E. H. (Member), General Electric Company, Schenectady, N. Y.

Archibald, J. F. (Member), Boston Edison Company, Boston, Mass.

Jones, W. L. Jr., General Electric Company, Schenectady, N. Y.

Judkins, F. H., General Electric Company, Pittsfield, Mass.

Marston, H. S., Westinghouse Electric and Manufacturing Company, Boston, Mass.

Maser, H. T. (Member), General Electric Company, Schenectady, N. Y.

Peterson, D. A., Dewey and Almy Chemical Company, Cambridge, Mass.

Salser, E., 45 St. Paul St., Brookline, Mass.

Schauer, A. H., George Keller Machinery Company, Buffalo, N. Y.

2. MIDDLE EASTERN

Ackor, W. R. (Member), E. C. Ernst, Incorporated, Washington, D. C.

Albrittain, M. C., Consolidated Gas, Electric Light and Power Company, Baltimore, Md.

Andrews, F. A. (Associate re-election), Consolidated Gas, Electric Light and Power Company, Baltimore, Md.

Bennett, F. C., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Bernhard, G. K. (Associate re-election), Board of Education, Cleveland, Ohio.

Bliss, D. S. (Associate re-election), Bliss Electrical School, Takoma Park, Md.

Bozarth, R. M., Philadelphia Navy Yard, Philadelphia, Pa.

Brandenburg, G. F., Consolidated Gas Electric Light and Power Company, Baltimore, Md.

Ciccarelli, W. E., I.T.E. Circuit Breaker Co., Philadelphia, Pa.

De Kiep, J. (Member), Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

De Shazo, J. S. (Associate re-election), Pennsylvania Power and Light Company, Hazleton, Pa.

Doyle, G. E., U. S. Engineer Corps, Cincinnati, Ohio.

Fitzgerald, J. W., Naval Research Laboratory, Sound Division, Washington, D. C.

Gray, J., General Electric Company, Philadelphia, Pa.

Hall, A. I. (Associate re-election), Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Hanson, E. T. (Associate re-election), United States Navy Yard, Philadelphia, Pa.

Hobart, T. D., Naval Research Laboratory, Anacostia, D. C.

Holmquist, A. S., The Ohio Public Service Company Massillon, Ohio.

Hunt, J. H. (Associate re-election), The Toledo Edison Company, Toledo, Ohio.

Kelly, E. L., Consolidated Gas, Electric Light and Power Company, Baltimore, Md.

Lamb, H. P., Adamson Machine Company, Akron, Ohio.

Lloyd, R. E., Navy Department, Bureau of Ships, Washington, D. C.

Shelhorse, C. H., Eastern Shore Public Service Company, Salisbury, Md.

Vargo, W. S., Westinghouse Electric and Manufacturing Company, Sharon, Penna.

Wenk, W. J., United States Navy, Mine Warfare Group, Planning Division, Navy Yard, Philadelphia, Pa.

Ziegenfuss, H. E. (Associate re-election), Consolidated Gas Electric Light and Power Company, Baltimore, Md.

3. NEW YORK CITY

Aster, A. K. (Associate re-election), Westinghouse Electric Elevator Company, Jersey City, N. J.

Bass, B. B., Gibbs and Hill, Incorporated, New York, N. Y.

Bostonian, E. T., General Electric Supply Corp., Brooklyn, N. Y.

Browning, L. C., Westinghouse Electric and Manufacturing Company, Newark, N. J.

Buchtenkirch, A. J., Guided Radio Corp., New York, N. Y.

Cliver, E. K. (Associate re-election), Celanese Corporation of America, Newark, N. J.

Crow, W. A., War Department, Signal Corps, Fort Monmouth, N. J.

Derfler, T. A., Bruce Engineering Company, New York, N. Y.

Duffy, E. H., Sperry Gyroscope Company, Incorporated, Brooklyn, N. Y.

Ekholm, J. F., Sanderson and Porter, New York, N. Y.

Feiring, F. C. (Member), 55 Vandam St., New York, N. Y.

Firth, F. G., Philips Metalix Corporation, Mt. Vernon, N. Y.

Fruit, P. L., Gibbs and Hill, Incorporated, New York, N. Y.

Haller, C. E., R. C. A. Manufacturing Company, Harrison, N. J.

Kozlowski, E. W., George G. Sharp, New York, N. Y.

Lederer, M. E. (Member), George W. Gates and Company, Incorporated, Franklin Square, L. I., N. Y.

Levin, R., Phillips Electrical Company, New York, N. Y.

Lewis, H. M. (Member), Hazeltine Corporation, Allenhurst, N. J.

Nelson, J. M. (Member), Westinghouse Electric and Manufacturing Company, Newark, N. J.

Oneal, L. E. (Member re-election), 15 Exchange Place, Jersey City, N. J.

Rienstra, A. R. (Associate re-election), Bell Telephone Laboratories, Incorporated, New York, N. Y.

Ritchie, A. E., Bell Telephone Laboratories, Incorporated, New York, N. Y.

Slack, C. M. (Member), Westinghouse Lamp Division, Bloomfield, N. J.

Slade, H. B., The Okonite Company, Passaic, N. J.

Soares, E. C. (Member re-election), 75 West St., New York, N. Y.

Stauber, T. W., American Transformer Company, Newark, N. J.

Stearn, F. A. (Member re-election), International Telephone and Radio Corp., Newark, N. J.

Steiner, O. C. (Member), Crocker Wheeler Electric Manufacturing Company, Ampere, N. J.

Stone, H. A., Jr., Bell Telephone Laboratories, Incorporated, New York, N. Y.

Valentine, D. H. (Associate re-election), New Jersey Bell Telephone Company, Newark, N. J.

Wennemer, G. P., Bell Telephone Laboratories, Incorporated, New York, N. Y.

Yeakle, R. B. (Associate re-election), General Cable Corporation, Bayonne, N. J.

Zezza, C. F., Gibbs and Hill, Incorporated, New York, N. Y.

4. SOUTHERN

Lindemann, W. E., Tennessee Valley Authority, Wilson Dam, Ala.

Mayer, L. F., Atmospheric Nitrogen Corporation, Hopewell, Va.

Nix, R. C., Tennessee Valley Authority, Douglas Dam, Jefferson City, Tenn.

Taylor, H. G. (Member), Southern Electric Service, Company, Greensboro, N. C.

Witkowski, T. T., U. S. Army, Corps of Engineers, c/o Postmaster, New Orleans, La.

5. GREAT LAKES

Doyle, F., Chicago District Electric Generating Corp., Hammond, Ind.

Herrmann, F. W., Columbia Broadcasting System, Minneapolis, Minn.

Hurd, F. (Member), 407 South Dearborn St., Chicago, Ill.

Malleris, C. F., Fairbanks, Morse and Company, Beloit, Wisc.

Reeb, C. A., Kerite Insulated Wire and Cable Company, Chicago, Ill.

Roney, R. M., War Department, Chanute Field, Ill.

Schulman, H. M., A. S. Schulman Electric Company, Chicago, Ill.

Schwarzlose, P. F., University of Illinois, Urbana, Ill.

Webb, F. G., Commonwealth Edison Company, Chicago, Ill.

Woo, A. S. F. (Associate re-election), Allis-Chalmers Manufacturing Company, West Allis, Wisconsin

6. NORTH CENTRAL

Blind, H. J., United States Naval Reserve, Casper, Wyo.

Wicks, F., University of Colorado, Boulder, Colo.

7. SOUTH WEST

Boudreaux, E. A., Southwestern Bell Telephone Company, Houston, Texas.

Gilbert, M. G. (Associate re-election), Empire District Electric Company, Joplin, Mo.

Gutsch, O. H., Southern Pacific Lines, El Paso, Texas.

LeVelle, A. S., Southwestern Bell Telephone Company, Dallas, Texas.

Meyer, E. C. (Member), Rural Electrification Administration, St. Louis, Mo.

Price, C. R., Rural Electrification Administration, St. Louis, Mo.

Scott, F. B. (Member), Rural Electrification Administration, St. Louis, Mo.

Stones, B. V. R., Washington University, Lindelland Skinker, St. Louis, Mo.

8. PACIFIC

Aufdemberg, O. H., Consolidated Steel Corporation, Wilmington, Calif.

Fellows, R. C. (Member), General Cable Corporation, Emeryville, Calif.

Keith, A. H., Consolidated Aircraft, San Diego, Calif.

McCarty, I. H. (Associate re-election), Butte Electric and Manufacturing Company, San Francisco, Calif.

Tahallon, R., Richmond Shipyard No. 1, Richmond, Calif.

9. NORTH WEST

Arents, C. A., Bonneville Power Administration, Portland, Ore.

Homschick, A. J., Northwestern Electric Company, Portland, Ore.

Mauldin, C. W., Army Air Force, First Communications Squadron (Det.), Gowen Field, Boise, Idaho.

Morrison, G. L., Washington Water Power Company, Spokane, Wash.

Morse, E. L., Washington Water Power Company, Spokane, Wash.

Smallidge, F. E., Washington Water Power Company, Spokane, Wash.

Spencer, J. C., Bonneville Power Administration, Portland, Ore.

10. CANADA

Bowlden, J. H., Canadian Westinghouse Company Limited, Hamilton, Ont.

Whelan, R. V., Electrical News and Engineering, Toronto, Ont.

Total, United States and Canada, 107

Elsewhere

de Lascurain, M. M. (Associate re-election), San Juan de Letran 13-413, Mexico, D.F., Mexico.

deOlarte, H. A. (Member), Compania Electrica Cuzco, Peru, South America.

Milne, J. C. (Member), Electric Construction Company, Wolverhampton, England.

Wilkinson, J. R. (Fellow), Ferguson Pailin Limited Manchester 11, England.

Total, elsewhere, 4

OF CURRENT INTEREST

Army and Navy Announce Details of College Training Programs

Joint Statement of the Secretary of War and the Secretary of the Navy on Utilization of College Facilities in Specialized Training for the Army and Navy

With the demands of a mechanical war and of steadily growing armed forces, the Army, Navy, Marine Corps, and Coast Guard are in need of a flow into their respective services of large numbers of young men who require specialized, educational, technical training. Their own facilities of teaching staff and equipment are not sufficient for these needs. The colleges and universities will have such facilities available. Consequently the armed services together have formulated plans to utilize for these needs to the maximum practicable extent the resources of these colleges and universities. In formulating these plans, they have had the benefit of fruitful consultation with many educators, and particularly the staff of the War Manpower Commission, a committee of the American Council on Education, and the Navy Advisory Council on Education. In the administration of these plans, the Army and Navy are counting on further assistance from the same sources.

Both plans contemplate that the educational training will be carried on while the men are on active duty, in uniform, receiving pay, and under general military discipline. The armed services will contract with colleges and universities which will furnish to the men selected by the services instruction in curricula prescribed by the services and also the necessary housing and messing facilities. Selection of those institutions which will be asked to undertake such contracts necessarily will be governed by their facilities for undertaking such responsibilities. The chairman of the War Manpower Commission after consultation with the Secretary of War and the Secretary of the Navy will prescribe the rules and regulations under which institutions of higher learning will be selected for this work. The actual selection will be made by a joint committee consisting of representatives of the armed services and the War Manpower Commission. In the event of failure on the part of the members of the committee to agree, the final decision will be made by the chairman of the War Manpower Commission.

The joint committee shortly will make announcement of its procedure for the selection of institutions and contracts under these plans. Meanwhile, it is requested that institutions themselves do not endeavor to get in touch with Government administrative organizations handling the matter. These organizations have a difficult administrative task ahead. The importance of their doing it in an orderly way will be manifest to all concerned. No institution will receive any advantage by departing from this procedure.

The plans of the Army and Navy, in their fundamentals, are the same, but there are certain variations in the plans of the respective services, because of differences in the laws affecting the two services, and in their requirements and procedures. These variations are in both the permanent plans and the plans for fitting the present members of their respective Enlisted Reserve Corps into the respective permanent programs. The plans will be operated in harmony and with mutual assistance.

Nothing in these new plans will affect existing contracts of the Army or Navy with educational institutions for facilities or training. It is probable that there will continue to be similar special arrangements that will not fall within the framework of the new plans. Such arrangements at present range from the bare leasing of physical facilities to provision for facilities, instruction, and use of equipment. The selection of colleges for such special arrangements will also be subject to rules and regulations prescribed by the chairman of the War Manpower Commission after consultation with the Secretary of War and the Secretary of the Navy and will be coordinated as between the Army and Navy by the joint committee.

The Army Specialized Training Program

(a). OBJECTIVE OF THE PLAN

The objective of the plan is to meet the need of the Army for the specialized technical training of soldiers on active duty for certain Army tasks for which its own training facilities are insufficient in extent or character. To that end the Army will contract with selected colleges and universities for the use of their facilities and faculties in effecting such training of selected soldiers in courses prescribed by the Army. This plan will enable the Army to make a selection for this training of qualified young men on a broad democratic basis without regard to financial resources.

(b). DESIGNATION OF SOLDIERS FOR TRAINING

1. Except as set forth in (g) below, the selection of soldiers for such training will be made from enlisted men who have completed or are completing their basic military training and who apply for selection for specialized training.

2. The selection of enlisted men for such further training will follow the general plan for the selection of enlisted men for Officers Candidate Schools with such additional methods of ascertaining qualifications as may be deemed appropriate after consultation with the American Council on Education.

3. All such selections will be under War Department control.

4. No enlisted man who has passed his 22d birthday will be eligible for selection under this program, except for an advanced stage of technical training.

(c). TRAINING UNDER COLLEGE CONTRACTS

1. All selected students will train in the grade of private (seventh grade).

2. Commutation allowances will not be permitted. Quarters and rations will be furnished under government contract.

3. Military training, organized under a cadet system, subordinated to academic instruction, within the time available, will preserve the benefits of basic training and provide for maintenance of discipline and a superior physical condition.

(d). SELECTION OF COLLEGES

In the selection of institutions, specific consideration will be given to the following:

1. Standards and equipment for the required instruction.
2. Adequacy of housing and messing facilities.
3. Minimum Army overhead.

(e). ACADEMIC STANDARDS OF STUDENTS

1. Standards of academic proficiency to be maintained by students who are trained under this program will be formulated after consultation with the American Council on Education.

2. In this connection, the method of initial selection of students will include such tests as reasonably will assure that the individual selected is intellectually, temperamentally, psychologically, and educationally capable of attaining these standards. Attrition and wastage must be held to a minimum.

3. In order to insure that individual students meet academic standards and to permit prompt relief and reassignment of those not suited for further specialized training, a system for continuous screening will be formulated and applied at all colleges participating in the program.

(f). STANDARDIZATION OF CURRICULA

1. To prepare for the particular technical tasks outlined by the various services

for which specialized training under this program is required, appropriate courses will be prescribed by the Army. Curricula will be prepared in consultation with the American Council on Education, looking to the speediest practicable training for such particular technical tasks. Varying with the nature of such tasks, the curricula will call for varying lengths of the period of training. They will also vary as to whether there are basic and advanced stages in any particular course of training. Soldiers selected for training may be assigned to any stage of a prescribed course which their previous training fits them to enter.

2. It is essential, if morale is to be preserved among those taking the program, that the soldier feel that his training, both at elementary and more advanced stages, is pointed directly at fitting him for some concrete military task for which he is being trained.

3. It is important, however, that in the selection and screening exceptional technical ability be identified and conserved, even though it may not prove to fit directly into Army tasks.

(g). SPECIAL PROVISIONS FOR SELECTION FOR TRAINING AND FOR THE TERMINATION OF THE ENLISTED RESERVE CORPS

1. Medical students (including dentist and veterinary) in the enlisted reserves will be called to active duty at the end of the first full semester, or substantially corresponding academic period, that begins in 1943 and will be detailed to continue courses of medical instruction under contracts to be made by the War Department with medical schools for facilities and instruction. Medical students who have been commissioned in the Medical Administrative Corps may, at the same time, resign such commissions, enlist as privates, and be detailed in the same manner as medical students in the enlisted reserve.

2. Premedical students in the Enlisted Reserve Corps, taking approved courses, will continue in an inactive status until the end of the first full semester, or substantially corresponding academic period that begins in 1943, and then will be called to active duty. Those selected at induction or at the completion of their basic military training for further medical or premedical training will be detailed for such instruction under the Army specialized training program.

3. Medical and premedical students, not in the Enlisted Reserve Corps, taking approved course, if inducted under Selective Service prior to the end of the first full semester, or substantially corresponding academic period, that begins in 1943, will be placed on inactive duty to continue such course until the end of that semester or period. They then will be called to active duty, at which time they may be detailed for further medical or premedical training under the Army specialized training program or assigned to other military duty.

4. Senior (fourth year) students taking advanced Reserve Officers' Training Corps work (including those in the Enlisted Reserve Corps) will be ordered to active duty upon graduation or upon completion of the first full semester, or substantially corresponding academic period, that begins in 1943, which ever is earlier. Upon entering active duty they will be ordered to their respective branch schools and commissioned upon successful completion of the course.

5. Junior (third year) students in the Enlisted Reserve Corps who are pursuing approved technical engineering courses will continue in an inactive status until the end of the first full semester, or substantially corresponding academic period, that begins in 1943, and then will be called to active duty. Those selected at the completion of their basic military training for further technical training will be detailed for such instruction under the Army specialized training program.

6. Junior (third year) students who are pursuing approved technical engineering courses and are not members of the Enlisted Reserve Corps will, if inducted prior to the end of the first full semester, or substantially corresponding academic period, that begins in 1943, be placed on inactive duty while continuing such technical engineering course until the end of that semester or period. They then will be called to active duty. Those selected at the completion of their basic military training for further technical training will be detailed for such instruction under the Army specialized training program.

7. All other Enlisted Reserve Corps students will be called to active duty at the end of the current semester, or substantially corresponding academic period, and, upon completion of basic training, will be eligible for selection for training under this program or for other military duty.

8. In the event that there appears to be occasion for selecting enlisted men for the Army specialized training program other than in the foregoing manner, requests for approval with reasons for the same will be submitted to the Chief of Staff.

(h). DISPOSITION AT THE END OF TRAINING

At the termination of specialized training, whether as a result of screening or completion of a course, the soldier will be selected for:

1. Further training in an Officer Candidate School.
2. Recommended for a technical noncommissioned officer.
3. Returned to troops.
4. In exceptional cases, detailed for very advanced technical training.
5. In very exceptional cases, be made available for technical work to be done out of the Army, but deemed to be highly important to the war effort.

(i). OPERATION OF THE PLAN

1. The assignment of soldiers to the Army specialized training program will begin during the month of February 1943, except for such action as may be required under the same prior to that time.

2. The Commanding General, Services of Supply, is responsible for the operation of the Army specialized training program.

Navy College Training Program

1. GENERAL PURPOSES

In order to provide a continuing supply of officer candidates in the various special fields required by the United States Navy, Marine Corps, and Coast Guard, a new plan for using the facilities of selected colleges and universities for training for Naval service has been established. Under this plan selected high-school graduates, or others of satisfactory educational qualifications, having established their proper mental, physical, and potential officer qualifications by appropriate examinations, will be inducted in the Navy as apprentice seamen or privates, United States Marine Corps, as appropriate, placed on active duty with pay, and assigned to designated colleges and universities to follow courses of study specified by the Navy Department.

This plan will permit selection of the country's best-qualified young men on a broad democratic basis, without regard to financial resources and thus permit the Navy to induct and train young men of superior ability for officers and specialists.

2. STATUS OF PRESENT ENLISTED RESERVES

At a date to be announced, all *V*-1, *V*-5, and *V*-7 reservists regularly enrolled in college as undergraduates will be placed on active duty, as apprentice seamen with full pay, subsistence, and uniforms. In order to carry the present programs to a conclusion and adapt them to the new program, it is contemplated that present enrollees in *V*-1 and *V*-7 will, when placed in active status, be assigned as follows:

(a). Those who, on July 1, 1943, have completed six or seven equivalent semesters* may complete two or one additional semesters.

(b). Those who at that date have completed five equivalent semesters will pursue a course of two additional equivalent semesters as outlined by the Bureau of Naval Personnel at an institution designated by the Navy.

(c). Those who at that date have completed four equivalent semesters will pursue a program of three additional equivalent semesters, as outlined by the Bureau of Naval Personnel at an institution designated by the Navy.

(d). Those who at that date have completed three equivalent semesters will pursue a program of four additional equivalent semesters, as outlined by the Bureau of Naval Personnel at an institution designated by the Navy.

(e). Those who at that date have completed one or two equivalent semesters will pursue a program of five or four additional equivalent semesters, respectively, as outlined by the Bureau of Naval Personnel at an institution designated by the Navy.

(f). *V*-1 and *V*-7 reservists who are undergraduates and who qualify as medical, dental, and theological students will be continued on active duty as apprentice seamen under instruction in accelerated curricula in approved schools and seminaries until completion of their professional studies.

(g). Engineering students who are in good standing in accredited engineering colleges will be allowed a total of *eight* equivalent semesters since their matriculation in college to complete their studies, regardless of the number of equivalent semesters completed as of July 1, 1942.

V-5 Reservists, who are college students and who so requested at the time of enlistment in or transfer to class *V*-5, may be deferred from assignment to specific aviation cadet training until the end of the college year current at the time of such enlistment or transfer.

* The expression, "equivalent semester," as used in this statement, means a term of continuous instruction, approximately 16 weeks in length.

As soon as present *V*-1, *V*-5, and *V*-7 students are placed on active duty, they will be required to spend full time in following courses of training appropriate to each student's previous course of study and as prescribed by the Bureau of Naval Personnel. These courses will be given throughout the calendar year.

Enlistments of college students who have not passed their 18th birthday will be accepted in the present *V*-1 program until March 15, 1943, only. Thereafter college students are eligible for selection for the new Navy college training program only through the regular procedures established for all other applicants.

3. STATUS OF NAVAL ROTC UNITS

Naval ROTC units will be continued and Naval ROTC students will be selected at the end of the first two semesters, from students inducted in the new program. The present Naval ROTC curriculum will be modified so that all professional subjects will be given subsequent to the first two semesters. All Naval ROTC students inducted in the Naval reserve will be placed on active duty.

4. PRESENT PROBATIONARY COMMISSIONED STUDENTS

At a date to be announced shortly, students now holding probationary commissions, on inactive duty in a deferred status, in the United States Naval Reserve will be permitted to resign and accept assignment to the college training program as apprentice seamen on active duty. At the satisfactory completion of their prescribed professional education they will be again commissioned in the USNR.

5. SELECTION OF TRAINEES

(*a*). High-school graduates or students having equivalent formal education who will have attained their 17th but not their 20th birthday at the time of enlistment or induction will be eligible for this program. Enlisted or inducted men with the above educational qualifications, who will have reached their 17th but not their 23d birthday, and who are recommended by their commanding officer, are eligible to apply for this program.

(*b*). Students will be selected normally during the senior year in high school on the basis of their officerlike qualifications, including appearance, physical fitness, high-school scholarship records. No applicants will be considered unless they are organically sound, without physical disabilities, have 18/20 vision, and evidence potential officer qualifications. Candidates who cannot meet these requirements are advised not to apply.

(*c*). Procedures for the selection of students, in conformity with the President's executive order on man power, dated December 5, 1942, are being prepared by the Bureau of Naval Personnel. Information covering these procedures will be made available in the future.

(*d*). Successful candidates will be permitted to indicate their preference as to colleges to which they wish to be assigned, and these preferences will be respected insofar as possible, within geographical limits and student availability within the area. No guarantees, however, can be made that a student's request for a given institution will be granted.

(*e*). Students will be permitted to express preliminary choice of the branch of service including the Marine Corps and Coast Guard at the time of assignment to the Navy college program, but this choice will not be binding. Final assignment will be based upon demonstrated ability and counseling during the first two semesters.

(*f*). The various geographical areas of the country will be assigned quotas on the basis of population.

(*g*). Men assigned to this program may be transferred at their own request to class *V*-5 at any time if otherwise qualified. Men in class *V*-5 may be transferred as needed to specialized aviation cadet training at any time during their year of training under this program.

6. ARRANGEMENTS WITH THE COLLEGES

(*a*). Contracts with the institutions will provide for training, housing, feeding, and medical service.

The contract with the institution will insure a definite minimum number of men.

Students may or may not be housed in groups, depending upon local conditions. It is the responsibility of the institution to see that satisfactory feeding and housing are maintained. The institution's contract will cover the cost of the same.

(*b*). The Navy will furnish each institution at least one officer for purposes of naval administration.

General instructions for discipline and routine will be issued by the Bureau of Naval Personnel, in order that procedures may be standardized insofar as local conditions will permit.

(*c*). A co-operating institution will be required to accept men ordered to it for training. At the same time each institution will be expected to maintain high standards of selectivity in examinations, instructions, and so forth, and to recommend transfer to other duty of students who fail to meet these standards.

7. CURRICULA AND REQUIREMENTS FOR TRAINING

The Navy will prescribe the curricula which are necessary to insure production of officer material for the various branches of Naval service, including aviation cadets, engineer and deck officers, engineer specialists, medical and dental officers, supply corps officers, and chaplains. Curricula will vary in length, depending on training requirements. With the exception of medical and dental officers, engineering specialists, and chaplains, the length will be from two to six equivalent semesters.

(*a*). Courses for the first two 16-week terms or the equivalent will be similar for all students and will emphasize fundamental college work in mathematics, science, English, history, drawing, and physical training. All students inducted in the new Navy college training program will receive instruction in naval organization and general naval orientation. The amount of time devoted to this work will not exceed three class hours per week during the first two semesters.

Outlines of all curricula will be prepared by the Bureau of Naval Personnel, with such assistance as may be required from representative educators or educational societies.

(*b*). If the college is satisfied that the student has covered adequately any of the subjects included in the curricula, proper substitutes will be permitted.

(*c*). The Navy will give achievement examinations at the end of the first two terms. The result of these examinations will be used in determining further assignments.

(*d*). Any student who fails to maintain a satisfactory standing in the course will be dropped from college and transferred to other naval duty.

8. ASSIGNMENT AT COMPLETION OF TRAINING

Upon satisfactory completion of college training all students will be assigned to appriate specialized training in the Navy, Marine Corps, or Coast Guard. Selection for this training will be based on student preference, counseling, and acceptance by the service concerned. If found qualified upon completion of this training, the students will be commissioned in the appropriate reserve.

Resolutions on Man Power Issued by Engineering Committee

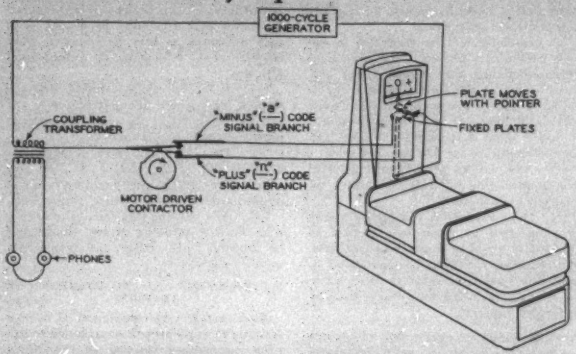
The consultative committee on engineering for the professional and technical division of the War Manpower Commission, under the chairmanship of R. E. Doherty (F '39), president of Carnegie Institute of Technology, Pittsburgh, Pa., recently passed two resolutions concerning engineering man power. The first is:

The committee recommends that the War Manpower Commission undertake immediately, with the co-operation of the War Production Board, a factual survey of shortages of professional engineering man power in war industries, and surpluses wherever they may exist, in order to establish a rational basis for planning a program for the most effective training and use of the limited engineering manpower.

The committee's second resolution follows.

Recognizing the necessity for a continuing flow of professionally trained men for war industries, especially for urgent developmental work in improving the quality and production of actual weapons and materials of warfare, this consultative committee on engineering for the professional and technical division of the War Manpower Commission, respectfully recommends that the chairman of the War Manpower Commission immediately take the necessary steps in order to provide temporary deferment from military service for those undergraduates in recognized engineering schools who are subject to Selective Service. Such deferment is necessary pending a more thorough study

"Audio Scale" May Open War Work to Blind



The radio-beam scale, developed by the Toledo (Ohio) Scale Company, is expected to make it possible for the blind to play a part in war production by weighing certain materials such as powder for fuses, mica for radio mechanisms, and buttons for uniforms accurately and rapidly. Alternating current of 1,000 cycles flows in tuneable double-branch circuit, with an earphone coupling transformer common to both branches. A motor-driven contactor switches the current alternately to the two branches so that the intermeshed "a" and "n" pulses are applied respectively to the minus and plus fixed plates of the scale indicator balancing condenser. At the desired weight, both signals are heard synchronized.

of the requirements of engineering man power both by war industries and the Armed Forces.

This recommendation confirms and re-emphasizes the resolutions made by the recent annual meetings of the American Society of Mechanical Engineers, the American Institute of Chemical Engineers, the Society for the Promotion of Engineering Education, and others, looking to the deferment of those young men who are already in engineering training and are maintaining satisfactory academic records. This is not a recommendation for class deferment but is a recognition of a temporary but critical phase of the manpower situation which requires prompt and decisive action to prevent serious crippling of the war program.

John C. Parker (F '12), AIEE past president, is AIEE representative serving on this committee.

Specialists Needed to Administer Controlled-Materials Plan

The United States Civil Service Commission recently began a nation-wide search for production specialists to administer the War Production Board's new Controlled-Materials Plan. The plan, designed to balance essential industrial production against available stockpiles of critical materials, will go into operation in 1943 (*EE, Dec. '42, pp. 630–1*).

Many hundreds of production and materials-control specialists whose experience demonstrates their ability to co-ordinate and schedule industrial production in certain fields are being called upon to make their services available wherever possible, according to the Commission's announcement. Applications, however, are not sought from persons already using their highest skills in war work.

Urgently needed are persons with industrial or engineering experience in the fields of copper, aluminum, carbon steel, and alloy steel. Also highly important to this program are those with such experience in

1. Machine tool and machinery production.
2. Electrical and communications equipment.
3. Transportation equipment, such as aircraft, ships, and railroad motive power, and rolling stock.
4. Engineering materials such as plastics, rubber, and construction materials.

Under the plan, specialists will be appointed to WPB, Navy, and other war agencies to assist in the allotment of critical materials going into military and essential civilian supplies and equipment. They will determine the material needs of manufacturers, schedule production, and follow up production to insure the flow of critical materials according to plan.

Production and materials-control specialist. Head specialists will receive $6,500 a year; others $4,600 and $5,600 a year. Many positions, however, must be filled at salaries ranging from $2,000 to $3,800 a year. Jobs are located in Washington, D. C., and throughout the nation. Persons interested may obtain the Commission's announcement 279 concerning the jobs from local representatives at first- and second-class post offices, or from the United States Civil Service Commission, Washington, D. C. No written test will be given, and there is no maximum age limit. Applications with the title "Production Control Specialist," or "Materials Control Specialist" inserted, must be filed with the Commission's Washington office and will be accepted until the needs of the service have been met. War man-power restrictions on Federal appointment of persons engaged in certain critical occupations in specified areas are contained in form 3989 posted in first- and second-class post offices.

Publications Tell How to Conserve Critical Materials

Within the last few months many articles pointing to ways of conserving critical materials have appeared in *Electrical Engineering* and other publications. The subcommittee on conservation of materials of the AIEE committee on co-operation with war agencies has prepared a list of articles of this kind which have come to its attention and which it is believed will be of general interest to members of the Institute.

AIEE PAPERS

Distribution Substations and Wartime Necessities, **F. C. Poage, M. W. Reid.** AIEE *Transactions*, volume 61, 1942, March section, pages 117–22.

Electric-Power Distribution Systems in Wartime **Philip Sporn.** AIEE *Transactions*, volume 61, 1942, March section, pages 105–6.

Emergency Overloads for Oil-Insulated Transformers, **F. J. Vogel, T. K. Sloat.** AIEE *Transactions*, volume 61, 1942, September section, pages 669–73.

Interim Report on Guides for Overloading Transformers and Voltage Regulators, **AIEE transformer subcommittee.** AIEE *Transactions*, volume 61, 1942, September section, pages 692–4.

Load Ratings of Cable—II, **Herman Halperin.** AIEE *Transactions*, volume 61, 1942, pages 930–42.

Overhead Distribution Systems in Wartime, **Harold Cole.** AIEE *Transactions*, volume 61, 1942, March section, pages 123–6.

Power Supply to Distribution Substations in Wartime, **H. P. St. Clair.** AIEE *Transactions*, volume 61, 1942, March section, pages 112–7.

Standardized Load-Center Unit Substations for Low-Voltage A-C Systems, **E. M. Hunter, J. C. Page.** AIEE *Transactions*, volume 61, 1942, July section, pages 519–25.

The Fundamentals of Industrial Distribution Systems, **D. L. Beeman, R. H. Kaufmann.** AIEE *Transactions*, volume 61, 1942, May section, pages 272–9.

Underground Distribution Systems in Wartime, **L. R. Gaty.** AIEE *Transactions*, volume 61, 1942, March section, pages 107–12.

OTHER PUBLICATIONS

General

Industrial Mobilization, **R. P. Patterson.** *Army Ordnance*, March–April 1942.

Material Standards in National Preparedness, **Colonel W. C. Young.** ASTM, August 1940.

Material Substitution and Supply List. Office of War Information, War Production Board. WPB 2112. (Lists over 500 materials ranked on basis of necessity and availability. List is revised periodically.)

Strategic Materials, **Captain G. K. Hoss.** *Army Ordnance*, July–August 1940.

World Minerals and World Politics, **C. K. Leith.** Whittlesey House.

Increasing Extent of Use of What We Have

Assisting the Customer to Make Maximum Use of His Existing Electrical Facilities, **E. A. Brand.** Edison Electric Institute *Bulletin*, April 1942.

Breaker and Switch Contacts Resurfaced With Silver Alloy. *Electrical World*, October 17, 1942.

Conservation of Linemen's Rubber Protective Equipment. **Roy M. Godwin.** Edison Electric Institute *Bulletin*, July 1942.

The Dual Rating of Electrical Apparatus, **P. L. Alger.** *Electrical Engineering*, December 1941, pages 569–71.

How Electric Utilities Are Solving Operating Problems Arising Out of the War. (A symposium of 142 cases.) *Electrical World*, May 30, 1942.

May Copper Work Harder, **Lee F. Adams.** *Electrical West*, November 1942.

Overmotoring—Almost a Crime, **L. A. Umansky.** *Blast Furnace and Steel Plant*. September 1942.

Results of Emergency Overload Tests on 24-Kv, 3-Conductor Paper and Lead Cables, **G. B. McCabe, Joseph Sticher.** Edison Electric Institute *Bulletin*. November-December 1942.

Supplying Kilovar Loads for War Conservation and Economy, **M. C. Miller.** Edison Electric Institute *Bulletin*, October 1942.

Utilizing Full Transformer Capacity Safely. *Westinghouse Engineer*, August 1942.

Vital Materials Conserved by Fusing and Banking of Transformers, **M. M. Levy.** *Electric Light and Power*, June 1942.

Making Minimum Use of Critical Materials

American Society For Testing Materials Standards and Emergency Standards.

Ceramic Insulating Materials, **Hans Thurnauer.** *Electrical Engineering*, volume 59, November 1940, pages 451–9.

Conservation of Materials for Defense Wiring, **H. R. Stevenson.** (*CNX* Wiring System.) Edison Electric Institute *Bulletin*, November 1941.

Critical Materials—Their Conservation by Use of Alternates, **John Horn.** *General Electric Review*, July 1942.

Doing a Bigger Job With Less (substitute materials.) **Alvin von Auw.** *Bell Telephone Magazine*, August 1942.

Evaluate Steel Pipe as A-C Conductor, **Stanley C. Killian.** *Electrical World*, April 18, 1942.

Forest Products Handbook. Forest Products Laboratory. Technique of Plywood, **Charles B. Norris.** Pitman Publishing Corporation.

Galvanized Steel as a Power Conductor, **Frederick M. Crapo.** *Electrical World*, September 19, 1942.

Handbook Dow Metal Magnesium Alloys. Dow Chemical Company.

Material Conservation (substitute materials), **Fredric Luther.** *Wire and Cable Products*, October 1942.

Metal Shortages and Their Effect on Line Hardware, **Earl H. Kendall.** Edison Electric Institute *Bulletin*, November 1941.

Modern Plywood, **E. F. Lancks, Thomas D. Terry.** Pitman Publishing Corporation.

National Emergency Steels. *Metal Progress*, October 1942.

Opportunities for Conservation of Critical Materials in Victory House Wiring and Industry, **J. F. Porter, Jr.** Edison Electric Institute *Bulletin*, April 1942.

Plastics in 1940. *Fortune*, October 1940. What Man Has Joined Together. *Fortune*, March 1936.

Proposed Tentative Alternative Bronzes. Society of Automotive Engineers *Journal*, June 1942.

Smaller Transformers by Forced Cooling, **W. G. James.** *Westinghouse Engineer*, August 1942.

Solders With Less Tin for Wipes and Joints. (Describes "victory" cable joint and summarizes experiences with low-tin wiping solders.) *Electrical World*, August 22, 1942.

Substitutions for Critical Materials. *Electrical Engineering*, volume 61, June 1942, pages 317–20.

Substitution and Conservation of Materials, **E. H. Tovee.** *The Canadian Purchaser*, December 1942.

Supplement to the 1940 National Electrical Code (Interim Amendments effective only during the war emergency).

Synthetic Fibres—The Growth of Rayon and the Rapid Rise of New Synthetics. *Rayon Textile Monthly*, May 1941, June 1941.

"Victory Joints" Conserve Tin (new technique for wiping joints in lead covered cables), **Fred C. Buerk.** *Telephone Engineer*, April 15, 1942.

Wartime Substitutions and Changes. (Specific instances of how familiar materials and methods are replaced with different things and ways.) *Electrical World*, October 17, 1942.

Getting Materials Back Into Circulation

Easing Your Priority Problems With Reclamation, **K. C. Campbell.** Edison Electric Institute *Bulletin*, August 1941.

Erie Shows the Way in Salvage Campaign. *Purchasing*, February 1942.

Getting in the Scrap Proves to be a Continuous Process *Electric Light and Power*, August 1942.

"Gold" in the Scrap Pile, **Ray Schmidt.** *Factory Management and Maintenance*, September 1942.

Machines Must Work for War—or Scrap! (A systematic survey to uncover scrap), **E. B. Robinson.** *Power*, October 1942.

Salvage From a Producer's Viewpoint, **C. R. Stevens.** *Steel*, October 12, 1942.

Salvage and Scrap Material Manual for the Utilities. Industrial Salvage Section, conservation division, War Production Board.

Sectional Conference on Reclamation and Salvage. Edison Electric Institute *Bulletin*, February 1942, March 1942.

We're in the Scrap. *Contact*, October 1942.

Problems for War and Peace Discussed by B. W. Clark

"We are fighting for peace and hoping that with peace will come the beginning of a new and better world," said B. W. Clark, vice-president of Westinghouse Electric and Manufacturing Company, in a recent address, "Problems Facing Industry for War and Peace," which he presented to the Producers' Council, November 17, 1942.

Important aspects of the peace, according to Mr. Clark, are:

"1. While a period of readjustment to peacetime conditions must take place, it should be no more difficult than our recent adjustment to wartime conditions.

"2. The people of a war-torn world, especially of the United States, are not going to give in to such a depression as we could visualize. They are fighting for freedom, security, and the good things of life, and they are going to have them.

"3. To the extent that industry is farseeing, courageous, and able, there should be a return to free enterprise . . . .

"4. The pent up demand for the goods of peace will be unprecedented. These goods are wearing out, and they are becoming obsolete. More new families have been launched in the last two years than in any similar period. They'll want homes—modern homes—equipped with modern conveniences.

"5. The means of purchasing will be there—in cash, bonds, and credit. The people can't spend their money now, and the consequent purchasing power for the future will be vast. The accumulations of debt to cover house buildings and repair, automobiles, refrigerators, and so forth—billions of dollars—are almost liquidated. The credits will be ready to finance new peacetime business."

Problems in future industrial activities will entail standards of building, now developed in a mass of individual codes which tend to increase building costs, slow construction, and confuse everyone concerned. In the interest of simplification, speed, and saving of critical materials, Federal restrictions and uniform standards have superseded these individual codes. "Every branch of this industry ought now, I believe," commented Mr. Clark, "to be considering sane standards of safety and permanence, and should be working towards sane and uniform codes that will enforce sound construction for each type of building, with due regard for the peculiar requirements of location, in the interest of lower costs, better understanding, and business-like administration."

Another problem is product research and design for the future. A long vista of improvement in design, manufacture, performance, and cost of homes, automobiles, appliances, and new facilities for making life simpler and easier following the war is visualized for the public by advertisers and writers of postwar predictions. Expansion in light metals, alloys, plastics, wood products, cement and concrete, and motor fuels points to the probability of a peacetime revolution. Mr. Clark warned against too rapid and too radical change in design.

Mr. Clark praised industry's response to the problems arising from war, a miracle wrought out of vast expansion of industrial equipment, quick adaptation to the requirements of new war machines, and technical advances.

"The figure of $13^1/_2$ billion dollars for 1942 construction speaks for itself. Doubled in dollars in two years, largely of the cheapest construction available for the given job, it is 15 per cent greater in dollars than the 1929 peak; and remember the 1929 peak was in high-cost office buildings, apartments, hotels, and so forth. The peak was reached after a gradual six-year climb," said Mr. Clark. He reminded members of the Producers' Council that experts expect a decline in new buildings to about eight billion dollars in 1943, with a further decline in later war years.

Mr. Clark quoted a War Production Board release to confirm his contention that the important business of repair and maintenance should be continued throughout war years. He predicted an increase of the problems of material procurement, man power, and transportation, the probability of discouraging news from the fronts, and the possibility of attack, but he also stated that industry was now able and determined to cope with any of these problems.

Electric Gauge Measures Thickness of Plating of Machine Parts

Portable electric gauges, which check to the thousandth of an inch the thickness of surface coatings of precision-machined plane and tank parts, without marring the parts, are being used in war plants to save time and materials, according to H. P. Kuehni, gauge expert of the General Electric Company. The lead-bronze, copper, silver, and heavy babbit linings on steel bearings and the chrome, nickel, and cadmium plating on other steel parts prevent corrosion and increase wearing qualities, and they must be accurate to a tiny fraction of an inch.

The main part of the gauge is a seven-pound portable indicating unit with a dial

marked in thousandths of an inch. A small cylindrical gauge head containing an electromagnet is connected to the indicating unit by a lightweight cable. The instrument is plugged into an ordinary a-c outlet.

When placed against a surface, the gauge head can measure the thickness of any nonmagnetic layer up to 0.3 inch thick and backed by steel. The head sets up electric currents in the instrument which vary in intensity with different layer thicknesses. By measuring the currents, therefore, the instrument can indicate the exact thickness on a dial large enough to be read at a glance at production-line speed.

Tungsten Production Increased by American Republics

Argentina is expected to increase its annual production of tungsten to about 3,000 tons, in order to fulfill its agreement signed in November 1941, to sell its exportable tungsten to the United States. Argentina's tungsten production in 1938 was approximately 2,000 tons, at that time about 3.5 per cent of the world's production. Bolivia, another chief producer of tungsten, signed a similar agreement with the United States.

Some tungsten is also produced in Peru, Mexico, Brazil, and Chile, and these American republics are increasing their production also to aid the United Nations war effort.

Formerly about 10 per cent of the world's tungsten (in addition to Argentina's share) came from the other Americas. But this proportion may have been changed in view of the necessity of developing new sources of supply with the closing of former sources in China and elsewhere.

Articles on Aircraft Instruments Available

A series of articles on the repair and upkeep of aircraft instruments, which appeared in the *Horological Journal* of London, England, recently, is being made available by Henry Paulson and Company to those in the United States who are interested in the subject. This company has offered to reproduce these articles for distribution to interested AIEE members. The articles reflect British experience in maintenance of aircraft instruments in combat service.

The series covers the following subjects: Fuel pressure gauges, oil pressure gauges, pressure-gauge calibrator, precision measuring, rate-of-climb indicator, altitude recorder, air-speed indicator, compass, repair of jewels and pivots in instruments, gyroscopic instruments, timing indicator, directional gyro, Sperry horizon, gyropilot, how the gyropilot operates, bank and climb gyro, how the gyropilot is used. Members interested in securing any of these articles should address their inquiries directly to Henry Paulson and Company, 37 South Wabash Avenue, Chicago, Ill.

New Rubber Plant. An annual production of more than 875,000 tons of synthetic rubber will be the quota for a new large government-financed plant to be located in Kentucky. Production operations on this plant have just begun, reports John L. Collyer, president of the B. F. Goodrich Company, Akron, Ohio. The plant ultimately will utilize butadiene made from alcohol and very soon will be producing general-purpose synthetic rubber for the war program.

Test Engines Produce Electricity

Operators in this soundproof booth are checking the performance of new airplane engines which are producing electricity during their test runs by being connected to generators instead of propellers. The equipment shown in the picture, developed by engineers of Pratt and Whitney Aircraft and General Electric Company, records readings of the engine's performance, transmitted along lines run from the engine under test to the dials and indicators. This power-recovery system has been installed in a number of engine factories throughout the United States (*EE Sept. '42, p. 402*).

JOINT ACTIVITIES

ASA Holds Annual Meeting; Elects Officers

The important role played by standards in the nation's war program was the principal theme of the annual meeting of the American Standards Association, held December 11, 1942, at the Hotel Astor, New York, N. Y., R. E. Zimmerman, ASA president, on the association's work during the past year and Joseph L. Weiner, deputy director of the War Production Board Office of Civilian Supply, who was guest speaker at the meeting, explained how the Government's policy of concentration of production is being followed, why it was adopted, and how it is likely to affect civilian production (*EE, Sept. '42, p. 489*).

Mr. Zimmerman in his report of ASA work said, "The launching of a great coordinated national effort was destined to call upon standards in proportion to the enormity of the task ahead. At no other time in its existence had this organization been confronted with such opportunities for service nor has it faced such responsibilities.

"An ever increasing regard for standards has been developing in Government agencies and in business circles. In a recent talk, a high-ranking official told us that one of the major difficulties which the American army has been encountering abroad is the lack of thoroughly standardized parts for repair work. There has been the further complication of coordination with the British and our other allies on the dovetailing of supplies."

Among standards to be issued in cooperation with the nation's war program by the ASA, Mr. Zimmerman listed those for safety shoes for both men and women which will save valuable war material and at the same time protect workers against

injuries; a standard for the protective lighting of industrial properties, which will aid in safeguarding factories from theft, sabotage, and subversive activities of all kinds; a comprehensive program of standards for materials and parts for military radio which are expected for the first time to unify the requirements of the Army, Navy, prime contractors, and subcontractors.

Mr. Zimmerman pointed out further that "a drastic simplification program for repair parts for civilian radio is also being started. This will insure the 'home' radios of our country being kept in good working order. Features of construction, definitions of quality and operating performance, set up under this program will enable Office of Price Administration satisfactorily to relate quality to price in future price orders."

In addition to specific work carried out by the ASA to assist in war production, Mr. Zimmerman stated that "much of the peacetime work of the association was immediately available for the war effort, for example, the more than 80 mechanical standards for parts, tools, bolts, screws, bearings, drawings were ready for instant use. The 70 safety standards for the protection of workers from industrial accidents, the many electrical standards for motors, wires and cables, insulators, switchgear, and so forth, were available at once for Government purchasing and for arrangements with subcontractors."

In another field the association has been able to assist the Government in setting up its safety program in industry by supplying safety standards to arsenals, companies filling Government orders, and government departments. At the request of the Committee on Conservation of Manpower, it printed a special group of safety standards and made them available, at cost, to students in Government supervised safety engineering courses.

Mr. Zimmerman dwelt briefly on new ASA memberships during the year. Fifty new companies joined during the summer months. Four new national groups affiliated during the year:

Metal Cutting Tool Institute; Timber Engineering Company (a subsidiary of the National Lumber Manufacturers Association); Textile Color Card Association; Committee on Consumer Relations in Advertising.

"In another direction," said Mr. Zimmerman, "it is gratifying to be able to announce that means have been found whereby the ASA is undertaking an extensive program of co-operation on standardization work with the other American countries" (see item this page).

In his address at the annual meeting, Mr. Weiner pointed out that preliminary surveys of industries which seem to be capable of contributing to the war program if they are concentrated, are now being concluded. He went on to say, "It is now estimated that only $1^1/_2$ per cent of the total steel expected to be produced in 1943 will go into consumer products. Nearly all of that will be required for the maintenance of houses and durable goods already produced and in use. Similar curtailments are necessary in the usage of other metals such as copper, aluminum, and so forth. Concentration may be necessary because the essential civilian supply is so small a proportion of the capacity of an industry that if the production were shared out among all the plants within the industry according to their past business, none could be kept going. In these circumstances essential civilian supplies can be maintained only by the concentration of their production in a few plants."

ASA officers for 1942–43 were elected at the meeting. They are:

President: R. E. Zimmerman, vice-president United States Steel Corporation (re-elected to serve a third term).

Vice-president: George S. Case, chairman of the board, Lamson and Sessions Company.

Chairman, Standards Council: H. S. Osborne (F '21), American Telephone and Telegraph Company, New York, N. Y. (re-elected).

Vice-chairman: E. C. Crittenden (M '22), National Bureau of Standards, Washington, D. C.

The following five organizations were elected to fill vacancies occurring on the board of directors:

1. American Petroleum Institute.
2. American Gas Association.
3. Fire Protection Group.
4. Association of American Railroads.
5. American Institute of Electrical Engineers.

ASA Establishes Inter-American Program

It is expected that trade and industrial development of the Americas will be furthered by a program of inter-American co-operation on industrial and engineering standards which was launched recently by the American Standards Association, New York, N. Y.

In the new program the ASA will exchange technical data in the development and use of standards with the other American republics, give them information on the standardization work being done in the United States, and provide them with Spanish and Portuguese translations of standards which would be especially valuable in developing their industry. It is hoped that through this program a thorough exchange of technical information within the Western Hemisphere will result.

Cyrus T. Brady, Jr., engineer and sales executive of the United States Steel Export Company, has been granted a year's leave of absence to act as field representative on this project of the ASA. Members of the ASA advisory committee which has been appointed to serve as a guidance group under the chairmanship of R. E. Zimmerman, president of the ASA and vice-president of the United States Steel Corporation, are as follows:

Lyman J. Briggs, director, National Bureau of Standards; E. F. Callahan, vice-president, International General Electric Company; Alexander V. Dye, economic consultant, National Foreign Trade Council; H. Greenwood, vice-president, United States Steel Export Company; T. W. Howard, department of manufacture, United States Chamber of Commerce; C. L. Warwick, secretary-treasurer, American Society for Testing Materials; John W. White (A '29), vice-president, Westinghouse Electric International Company; Carroll L. Wilson, director, Bureau of Foreign and Domestic Commerce; J. T. Wilson, president, Export Managers Club.

Latin American countries have already shown interest in North American standards and have asked the ASA to supply them with further information. National standardizing bodies are already in operation in Argentina, Brazil, and Uruguay, and in other Latin American countries government departments and engineering societies are working on standardization. Furthermore there is a South American committee of which the function is to promote work on standards in the ten South American republics.

United Engineering Trustees, Inc. Elects Officers; Issues Report

At the annual meeting of the United Engineering Trustees, Inc., held October 22, 1942, the following officers for the year 1942–43 were elected: *president*, Albert Roberts (re-elected); *first vice-president*, F. Malcolm Farmer (F '13); *second vice-president*, Arthur S. Tuttle; *treasurer*, Arthur S. Tuttle (re-elected); *assistant treasurer*, W. D. B. Motter, Jr. (re-elected); *secretary* and *general manager*, John H. R. Arms (re-elected). The executive committee consists of the president, the two vice-presidents, J. P. H. Perry, W. D. B. Motter, Jr., and Walter Kidde.

Members of the board of trustees of UET for 1942–43 are:

Terms expiring October 1943
A. S. Tuttle, ASCE
Albert Roberts, AIME
Walter Kidde, ASME
C. E. Stephens, AIEE

Terms expiring October 1944
C. E. Trout, ASCE
W. D. B. Motter, Jr., AIME
K. H. Condit, ASME
E. S. Lee, AIEE

Terms expiring October 1945
A. L. Queneau, AIME
F. M. Farmer, AIEE

Terms expiring October 1946
J. P. H. Perry, ASCE
H. A. Lardner, ASME

Members of the finance committee are:

Walter Kidde, *chairman*	H. A. Lardner
Arthur S. Tuttle	C. E. Stephens
A. L. Queneau	Albert Roberts, *ex officio*

Members of the real-estate committee are:

Kenneth H. Condit	A. L. Queneau
E. S. Lee	C. E. Trout
J. P. H. Perry	Albert Roberts, *ex officio*

United Engineering Trustees, Inc., was organized in 1904 to manage property and funds held jointly by the four national Founder Societies: American Society of Civil Engineers, American Institute of Mining and Metallurgy, American Society of Mechanical Engineers, and American Institute of Electrical Engineers. The UET maintains two departments, the Engineer-

ing Societies Library and The Engineering Foundation, reports of which appear elsewhere in this issue. The corporation (UET, Inc.) manages the Engineering Societies Building and all trust funds placed with UET, Inc.

ANNUAL REPORT

The annual report of UET, Inc., for the year ending September 30, 1942, has been submitted to the AIEE and the other participating societies by Albert Roberts, president. Essential substance of the report follows.

The entry of the United States into the war shortly after the beginning of the last fiscal year has created additional problems and difficulties in the conduct of the affairs of the corporation.

A considerable program of renovation of the Engineering Societies Building was under way, supplies for which became subject to war priorities, and prices rose on those materials which were obtainable. However, the work was sufficiently advanced so that, despite some delay, it was completed during the year at a moderate increase in cost over the original appropriations. Results have been very gratifying both to the occupants and to the board of trustees of UET.

The operating financial position was adversely affected, in that labor costs and operating material costs have risen and income from rental of halls and auditorium has decreased, as these have been used largely for educational meetings attended by young men, many of whom are now engaged in the war effort. These adverse effects will be greater in the ensuing fiscal year.

Financial conditions and security prices suffered further dislocations during the year, and new problems have arisen. Nevertheless, UET security holdings, under the management of the finance committee, with the co-operation of our financial advisers, have improved in quality. As in the past year, all securities are held by the Chemical Bank and Trust Company as custodian.

The depreciation and renewal fund at the end of the year stood at $434,239.48, after receipt of the appropriation of $20,000 from operations, as for some years past, and the income from its investments, less outlays for renovation and improvement made during the year, totaling $41,496.75.

The corporation acts as treasurer for the Engineers' Council for Professional Development, and is custodian of the relief funds of Engineering Societies Personnel Service, Inc., and funds of the John Fritz Medal Board of Award and of the Daniel Guggenheim Medal Board of Award. It is also custodian of contributions from outside organizations aiding researches by the Engineering Foundation.

During the summer of 1941 renovation had been started in various parts of the Engineering Societies Building which after 35 years of service to the societies required repairs or renewal. This work was retarded by the increasing difficulty in obtaining materials, and completion ran well into 1942. One of the most striking improvements was the elimination of the false skylight illumination in the auditorium and the substitution of a safer means of providing more pleasing and more even illumination of adequate intensity.

Additional expenditures beyond the budget were incurred during the year in the amount of approximately $2,000 for the purchase of war-damage insurance on the building and for fire-fighting and safety equipment which under civilian defense laws became mandatory. In addition, maintenance supplies were purchased ahead as available, which increased the year's expenditures but which should reflect a corresponding decrease in the coming year.

On the income side, revenue from the meeting halls fell about $2,000 short of expectations owing to cancellation of scheduled meetings and classes due to war conditions. It is heartily urged that the societies utilize their building to the maximum of their requirements, and thus augment UET income.

Insurance inspectors report the building is in excellent physical condition. The corporation was fortunate in having the fire-insurance rate on the building further reduced, the resulting rates being the lowest given to any property of its class. Fire, extended coverage, liability and compensation insurance are carried, to which was added, on July 1, war-damage insurance.

All available space in the building is occupied by the Founder Societies and associates.

The 1941 annual report (*EE, Jan. '42, pp. 56–7*) recorded that the opinions of architects obtained at that time made it evident that the cost of major changes in the building to make it more nearly meet the present needs would not be justified by the possible benefits.

In pursuit of this general subject an extensive review of the condition and value of the building and property in relation to the depreciation and renewal fund has recently been concluded and a report has been transmitted to the Founder Societies.

The time will come when the war and ensuing readjustments being over, participating societies may feel warranted in replacing the present quarters with new quarters. The roster of the four societies includes many, if not the majority, of those largely responsible for the creation and operation of all the basic facilities of modern life, from the production of the necessary raw materials to final utilization and operation in their finished form. With this talent available it would seem that only organization is needed in order to achieve this end.

Engineering Foundation Report Issued; Officers Elected

The following officers for the year 1942–43 were elected at the recent annual meeting of The Engineering Foundation, joint research agency of the Founder Societies: *chairman*, A. L. Queneau; *vice-chairman*, Kenneth H. Condit; *director*, Edwin H. Colpitts (F '12) (re-elected); and *secretary*, John H. R. Arms. Members of the executive committee, in addition to the chairman, vice-chairman, and secretary of the Foundation are: J. P. H. Perry, W. I. Slichter (F '12), and C. E. Stephens (M '22).

Members of the Foundation board for 1942–43, with expiration dates of terms, are:

Trustees elected by the board of trustees of UET, Inc.

K. H. Condit, ASME, 1943
C. E. Stephens, AIEE, 1943
J. P. H. Perry, ASCE, 1944
A. L. Queneau, AIME, 1945

Ex officio, president, UET, Inc.

Albert Roberts

Members nominated by Founder Societies

J. D. Justin, ASCE, 1943
E. M. T. Ryder, ASCE, 1946
A. A. Potter, ASME, 1943
Edwards R. Fish, ASME, 1944
G. D. Barron, AIME, 1944
F. F. Colcord, AIME, 1946
F. M. Farmer, AIEE, 1943
W. I. Slichter, AIEE, 1944

Members-at-large

J. V. N. Dorr, AIME, 1943
R. H. Chambers, ASCE, 1943
O. E. Buckley, AIEE, 1946

Members of the research procedure committee are:

K. E. Condit, *chairman*, ASME
E. M. T. Ryder, ASCE
H. E. Wessman, ASCE
W. M. Peirce, AIME
C. L. W. Trinks, ASME
L. W. Chubb, AIEE

Chairman Queneau was appointed to represent the Foundation on the executive board of the National Research Council.

The personnel of other committees as appointed or reappointed at this meeting is as follows:

Iron Alloys Committee

George B. Waterhouse, *chairman and director*, professor of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass., AIME.

Lyman J. Briggs, director, National Bureau of Standards, represented by J. G. Thompson, senior metallurgist, National Bureau of Standards, Washington, D. C.

R. R. Sayers, director, United States Bureau of Mines represented by R. S. Dean, assistant director, United States Bureau of Mines, Washington, D. C.

James T. Mackenzie, chief metallurgist, American Cast Iron Pipe Company, Birmingham, Ala., American Foundrymen's Association.

John Johnston, director of research, United States Steel Corporation, Kearny, N. J. American Iron and Steel Institute.

James H. Critchett, vice-president, Union Carbide and Carbon Research Laboratories, Inc., New York, N. Y., American Electrochemical Society.

Bradley Stoughton, professor emeritus, Lehigh University, Bethlehem, Pa., American Society for Metals.

Jerome Strauss, vice-president, Vanadium Corporation of America, New York, N. Y., American Society for Testing Materials.

T. H. Wickenden, assistant manager, development and research, The International Nickel Company, Inc., New York, N. Y., Society of Automotive Engineers.

Wilfred Sykes, president, Inland Steel Company, Chicago, Ill. member-at-large.

Frank T. Sisco, *consultant*, assistant secretary, AIME, New York, N. Y.

R. E. Zimmerman, vice-president, United States Steel Corporation of Delaware, Pittsburgh, Pa.

William Spraragen, *executive secretary*, Welding Research Council, The Engineering Foundation, New York, N. Y.

Welding Research

Comfort A. Adams, *chairman*, consulting engineer, E. G. Budd Manufacturing Company, Philadelphia, Pa.

Harry C. Boardman, *vice-chairman*, director of research, Chicago Bridge and Iron Company, Chicago, Ill.

A. S. Albright, acting chief of research, Detroit (Mich.) Edison Company.

David Arnott, vice-president, American Bureau of Shipping, New York, N. Y.

Everett Chapman, president, Lukenweld, Inc., Coatesville, Pa.

O. U. Cook, assistant manager, department of metallurgy, inspection and research, Tennessee Coal, Iron and Railroad Company, Birmingham, Ala.

J. H. Critchett, vice-president, Union Carbide and Carbon Research Laboratories, Inc., New York, N. Y.

J. J. Crowe, assistant to vice-president and operating manager, Air Reduction Sales Company, New York, N. Y.

C. L. Eksergian, chief engineer, Budd Wheel Company, Detroit, Mich.

A. J. Ely, mechanical engineer, Standard Oil Development Company, Elizabeth, N. J.

F. H. Frankland, director of engineering, American Institute of Steel Construction, New York, N. Y.

T. S. Fuller, works laboratory, General Electric Company, Schenectady, N. Y.

Isaac Harter, vice-president, Babcock and Wilcox Company, New York, N. Y.

D. S. Jacobus, advisory engineer, Montclair, N. J.

G. F. Jenks, Taylor Winfield Corporation, Warren, Ohio.

Arthur E. Pew, vice-president, Sun Oil Company, Philadelphia, Pa.

A. C. Weigel, vice-president, Combustion Engineering Company, New York, N. Y.

Clyde Williams, National Defense Research Committee, Battelle Memorial Institute, Columbus, Ohio.

A. R. Wilson, engineer of bridges, Pennsylvania Railroad, Philadelphia, Pa.

Seventeen researches bearing on war work were endorsed by the board for support by grants during its fiscal year 1942–43. These include investigations in the fields of civil, mining and metallurgical, and mechanical and electrical engineering, covering various problems of soil mechanics and foundations, hydraulics, alloys of iron, critical pressure steam boilers, fluid meters, cold rolling steel, insulating oils and cable saturants, and welding. Professional development of the engineer also received the recognition of the board by a grant toward the work of the Engineers' Council for Professional Development.

ANNUAL REPORT

The salient points of the annual report of The Engineering Foundation as submitted by Chairman O. E. Buckley (F '29) to the AIEE and the other Founder societies follows.

The Engineering Foundation, established in 1914, completed its 28th fiscal year on September 30, 1942. The book value of the capital funds of the Foundation on September 30, 1942, was $952,000, a slight reduction from that of a year previous. The income has continued to suffer reduction due to lower prevailing interest rates. As a partial offset to this loss of income, it has been possible to reduce administrative and general expenses materially.

It has been the policy of the Foundation for many years to contribute to a considerable number of projects in diverse fields of engineering. This policy has been continued, but projects have been reconsidered with regard to their bearing on the war, and have been encouraged only in so far as they appear to contribute to the war effort. In several cases, grants which have been provided have not been utilized fully because of withdrawal of personnel to more direct war activities. It is expected that this trend will continue during the course of the war, and on that account it may be impracticable to make full use of the Foundation's income on projects helpful to the national cause. This is particularly the case in view of the Government's willingness to support research projects which can be demonstrated as important to the war effort.

During the year, work has progressed on 15 projects, comprising 21 separate problems. For the ensuing year, grants were recommended for the continuation of work on 11 problems and the initiation of 2 new projects.

Summaries of the research projects which were sponsored by the Foundation and with which the AIEE has been directly associated follow:

Stability of Impregnated-Paper Insulation. (Foundation grant, $1,000. Chairman, Doctor John B. Whitehead, Johns Hopkins University, Baltimore, Md.)

This research project has been supported by The Engineering Foundation for the past six years. No extension of support beyond the year 1941–42 has been received. During that year the feature of outstanding importance was the continuation of the study of the influence of paper density in impregnated-paper insulation for high-voltage service. These further studies have emphasized the results of studies in foregoing years, that the use of higher-density papers results in a shortening of life and lowering of dielectric strength in this type of insulation. This result has been unexpected by many cable manufacturers and will undoubtedly lead to modification and changes in the design of important types of high-voltage cables and capacitors.

Another important result has been the clarification of the open question of the influence of oil viscosity on impregnation, and life, and dielectric strength of this type of insulation. The less viscous oils have a markedly superior influence on life and dielectric strength.

The studies on the origin and progress of failure under high stress, utilizing an improved method for detecting the first presence of internal gaseous ionization, have been extended and a much clearer picture is now available of the origin and cause and process of failure.

Any report on this project would not be complete without expressing the opinion that Doctor Whitehead has done very important work in his studies of insulation and more particularly on impregnated-paper insulation. As the advisory committee has stated in its report, "The experimental studies have been conducted with a high degree of experimental skill and the results are characterized by accuracy and uniformity. While the program originally contemplated has been in large measure completed, certain of the results obtained, particularly those relating to paper density, high-stress internal ionization as the origin of failure, impregnation temperature versus dielectric strength and life, the limitations of the open tank in laboratory studies, all indicate the desirability that the work can be carried further."

It is certainly true that to a very high degree, Doctor Whitehead's work has stimulated research activities on the part of a number of workers in other organizations.

During the year in connection with this work the paper, "The Dielectric Strength and Life of Impregnated-Paper Insulation—III," by J. B. Whitehead (AIEE *Transactions*, volume 61, 1942, August section, pp. 618–22) was presented.

Insulating Oils and Cable Saturants. (Foundation grant, $1,500. Chairman, Herman Halperin, assistant equipment and research engineer, Commonwealth Edison Company, Chicago, Ill.)

The problem undertaken involved primarily the study of the electrical stability of electrical insulating oils under limited oxidation conditions. In this connection a new type of test has been developed. It is believed that it duplicates service conditions in oil-impregnated paper-insulated cables and in sealed transformers. In this test, definite and controlled amounts of oxygen are made available to the oil. These amounts vary from residual amounts, to amounts due to normal solubility of air in oil, and to larger amounts. Operating performance of oil-paper cables has, in certain cases, shown power-factor increases of the insulation which have been serious and impossible to explain, and it is believed that the test referred to will give important aid in the control of this problem. While electrical loss or power factor is not of prime importance for many types of oil-filled electrical equipment, it is the most sensitive known criterion for a stability test.

The work for the past fiscal year has included the following:

Tests on specially refined samples of oils supplied by the Gulf Research and Development Company and by the Shell Petroleum Corporation. These samples have been prepared to determine the effect of different refining procedures and the hydrocarbon constituents of the oils.

Tests on commercial insulating oils currently finding application in practice are made for purposes of correlation of the project's test results with results in service.

The characteristics of mineral oils, in general, are changed radically by the addition of small amounts of addition compounds. This procedure with respect to mineral oils is somewhat analogous to alloying for metals. For this purpose, the Gulf Research and Development Company has supplied a wide range of inhibitors and sulphur compounds of known structure.

The important results, from a practical point of view are as follows:

The degree and type of refining greatly

influences the electrical stability of the oils.

Certain addition compounds can very greatly influence the characteristics of an oil. It is believed that further improvement in the characteristics of electrical insulating oils will be obtained from this procedure. These addition compounds are added in amounts corresponding to a few hundredths or a few tenths of a per cent. In certain cases quite satisfactory results have been obtained using such compounds. However, it is rather difficult to obtain a compound to produce desirable characteristics for a wide range of service applications.

Welding Research Committee. (Foundation grant, $5,000. Chairman, Doctor Comfort A. Adams, E. G. Budd Manufacturing Company, Philadelphia, Pa.)

During the year 1941–42 the work of the Welding Research Committee has continued to be closely related to the war effort. Its activities are organized with the definite thought in mind of solving the many important welding problems that are raised in connection with manufacture and production for the armed services. Fortunately, the committee began to gear its efforts to national defense about two years ago, and the value of this head start is extremely important.

The fundamental research division, for example, realizing that it would be necessary to predict the weldability of any new steel, and to specify the exact procedure to follow in order to get the best results, outlined a comprehensive fundamental research program and by initiating such a program, in spite of serious financial obstacles, saved at least nine months of precious time.

The industrial research division has organized a number of new projects and extended its activities, especially in the field of aircraft welding. It has co-operated with, and assisted the National Advisory Committee for Aeronautics in the organization of numerous welding researches being carried out by that committee. It has also co-operated with the National Research Council and the National Defense Research Committee in furnishing information as to existing researches and the need for additional work. Several projects have been recommended through the Council and are being financed by the National Defense Research Committee. Close contacts have been maintained with the War and Navy Departments and other Government agencies interested in welding. The division's operations have been directed to problems directly related to war production.

The Foundation grant as in the past years was allocated to the fundamental research division and a brief reference to this division's work follows:

A comprehensive program on weldability under the auspices of the fundamental research division is well under way and nearing completion. The results of this research investigation will enable one to predict the weldability behavior of any new steel, and to indicate suitable procedures for welding any thickness of material under different climatic conditions. These investigations have been conducted at Lehigh University, Rensselaer Polytechnic Institute, Massachusetts Institute of Technology and Columbia University. The government, through the National Defense Research Committee, has appreciated the importance of this work in the war effort, and is financing the greater portion of it to the extent of some $29,000 a year. This sum is in addition to approximately $13,000 a year expended under the jurisdiction of the division.

A start has been made on studying the underlying phenomena of residual stresses and their behavior under service conditions. Preliminary pronouncements have been made in some special cases, as for example, what happens to residual stresses when plastic flow is possible. These experiments must be continued to cover more restrained conditions and suddenly applied loads.

The division continues to encourage research work in the different universities of this country. A great deal more can be done, and should be done, if funds are made available. Contact is being maintained with some 30 or more universities involving some 50 professors and instructors.

Special Accounts. The United Engineering Trustees, Inc., for The Engineering Foundation is custodian of seven accounts kept separate from that of the main committee:

Structural steel welding committee.
Carbon steel weldability research committee.
Weld stress committee.
Literature division.
Aircraft welding committee.
Resistance welding committee.
High alloy steels committee.

LIBRARY • • • • • •

OPERATED jointly by the AIEE and the other Founder Societies, the Engineering Societies Library, 29 West 39th Street, New York, N. Y., offers a wide variety of services to members all over the world. Information about these services may be obtained on inquiry to the director.

Board and Officers of Library Elected; Annual Report Issued

At the recent annual meeting of the United Engineering Trustees, Inc., W. A. Del Mar (F '20) was appointed chairman of the board of the Engineering Societies Library for 1942–43 and J. K. Finch, vice-chairman. Harrison W. Craver was reappointed director of the Library and secretary of the board.

Members of the Library board are as follows:

Terms expiring October 1943
C. E. Trout, ASCE
E. F. Church, Jr., ASME
G. L. Knight, AIEE
W. D. B. Motter, Jr., member board of trustees, UET

Terms expiring October 1944
J. K. Finch, ASCE
J. W. Lait, AIME
A. R. Mumford, ASME
W. A. Del Mar, AIEE
G. F. Felker, member-at-large

Terms expiring October 1945
Edward P. Hamilton, ASCE
A. T. Hastings, AIME
John Blizard, ASME
W. I. Slichter, AIEE
S. H. Ball, member-at-large

Terms expiring October 1946
Thomas T. Read, AIME
Robert H. Barclay, member-at-large

Ex officio
G. T. Seabury, secretary, ASCE
A. B. Parsons, secretary, AIME
C. E. Davies, secretary, ASME
H. H. Henline, national secretary, AIEE
H. W. Craver, director, Library

Members of the executive committee for 1942–1943 are:

E. P. Hamilton — A. T. Hasting
E. F. Church, Jr. — W. I. Slichter

ANNUAL REPORT

The annual report of the Engineering Societies Library for the year ending September 30, 1942, has been submitted to the AIEE and other Founder Societies. Essential substance of the report follows.

The past year has been one of unusual activity, during which the work of the Library has reflected directly the burdens placed upon engineers by military needs. The inquiries have been many and varied; most of them have called for the quickest possible answers, and many, unfortunately, asked for information so recent that it was not yet in print. As in the preceding year, a notable feature was the extent to which engineers have been detached from their customary fields of work and are being compelled to orient themselves in new ones.

To such men the library has offered help to the extent of its possibilities. Book lists have been supplied and books have been lent. Much periodical literature has been cited and copied. Where inquiries fell outside the scope of the work of the library, an endeavor to suggest other courses of information was made.

An outstanding event of the year has been the use made of the library by the military authorities. There has scarcely been a day when members of Government bureaus were not engaged in research work here, and the advice of the staff has been constantly sought in sources of information and methods of searching. Loans to Government departments have been numerous. In addition, the chief indexer has been lent to a Government bureau to assisist in devising a permanent system of indexing for military purposes.

It has been a source of great satisfaction to find how satisfactorily the collection meets the calls upon it. The large collection of foreign periodicals has proved very valuable and the catalog has answered requirements very effectively. A considerable number of periodicals appear to be available in very few other places.

During the year fluorescent lamps were installed in the reading room, with marked improvement. The lighting at night is now thoroughly satisfactory. In January 1942 work was begun upon a Japanese–English technical glossary, with the aid of a grant from the Rockefeller Foundation.

Operation of Library

Maintenance revenue	$47,967.21	
Maintenance expenditures	43,864.04	
Credit balance for year 1941–42	4,103.17	
Credit balance from previous years	7,279.62	
Credit balance September 30, 1942		$11,382.79
Service bureau revenue	$11,398.45	
Service bureau expenditures	9,749.58	
Credit balance for year 1941–42	1,648.87	
Credit balance from previous years	$10,826.01	
Less transfer to LSB reserve fund	7,500.00	3,326.01
Credit balance September 30, 1942		4,974.88
Total net operating credit balance cumulated to September 30, 1942		$16,357.67

The want of such an aid to translators has long been felt by the director, and the lack of such a glossary has been felt acutely since the outbreak of war with Japan. Work is being pushed as rapidly as possible, but will probably require another year for completion.

During the year 23,734 persons have visited the library and 11,648 others have made use of it in other ways. Searches to the number of 103 have been made and 35 translations have been prepared. Photostats totaling 31,254 and 64 microfilms were made for 3,046 persons. Telephone requests for assistance numbered 6,097 and mail inquiries, 1,717.

It is worthy of note that the use from a distance was 32 per cent; that is, about every third person used the library from a distance. In 1941 this figure was 28 per cent and it has been growing steadily for a number of years. It is gratifying to see this increasing appreciation of the service by those at a distance, unable to visit the library. To encourage this use, the rules governing loans to members were liberalized still further. An increase of loans of 25 per cent above 1941 resulted.

While the publication of technical books in the United States has greatly increased, the great part of this output has been books for mechanics and not for engineers. With foreign book sources cut off, the number of desirable books has been decidedly less. Receipts during the year were 10,163 books, pamphlets, and so forth. Of these 5,523 proved desirable accessions and were added to the permanent collection.

As in previous years, many gifts were received from members and other friends, to whom sincere thanks are tendered. The estate of John Hays Hammond presented a large collection of periodicals and reports on mining and geology. The Library of the Massachusetts Institute of Technology presented a valuable group of bridge specifications. Many gifts have come from the National Research Council and the Society of Automotive Engineers. Sanderson and Porter, New York, N. Y., and Newell, Spencer, and Safford, New York, N. Y., donated useful engineering material. A large library was received from the estate of William T. Wallace. Doctor D. B. Steinman presented the original manuscript of "Bridges and Their Builders" by D. B. Steinman and S. R. Watson.

The library has continued to receive frequent substantial gifts from the editorial departments of the McGraw-Hill Publishing Company. It has also had hearty cooperation from many national associations of engineers and industrialists.

The number of books reviewed for the official publications of the Founder Societies was 498.

On October 1, 1941, the library contained 152,263 volumes, 7,755 maps, and 4,492 searches. Corresponding figures at the end of the fiscal year 1941–42 are 154,770 volumes, 7,845 maps, and 4,525 searches, a total of 167,140 items.

Continued efforts to dispose of duplicates by gift to other libraries or by sale have reduced the number to about 11,000 volumes and pamphlets.

About 20,000 cards were added to the periodical index, which now contains over 276,000 carefully classed references to articles on all branches of engineering.

The budget established for general operation was $46,137.00, of which amount $37,636.92 was provided by the Founder Societies on a membership basis, as follows:

American Society of Civil Engineers	$ 9,943.92
American Institute of Mining and Metallurgical Engineers	8,074.68
American Society of Mechanical Engineers	9,356.88
American Institute of Electrical Engineers	10,261.44

Expenditures from this budget were $43,864.04, of which $7,439.69 was spent for books and other equipment of permanent value. Service Bureau receipts for special service were $11,398.45. Its expenses were $9,749.58.

OTHER SOCIETIES •

Eta Kappa Nu Award Postponed

The award organization committee of Eta Kappa Nu has announced the discontinuance of its recognition award until after the war because of the impossibility of determining the details of the work of many of the most outstanding young electrical engineers of today. When the granting of the award is resumed, it is expected that it will be given for the year 1942, and possibly for intervening years. Candidates whose records are now on file will be considered eligible whenever the award is made again although at that time their age and graduation date may be beyond the usual limits.

Future Meetings of Other Societies

American Institute of Mining and Metallurgical Engineers. Annual meeting, February 14–18, 1943, New York, N. Y.

American Society of Civil Engineers. Annual meeting, January 20–22, 1943, New York, N. Y.

ASRE Officers Elected

Charles R. Logan, representative of the Superior Valve and Fittings Company of Pittsburgh, Pa., has been elected president of The American Society of Refrigerating Engineers, and was inducted into office on December 2, 1942, at the closing session of the Society's 38th annual meeting at the Hotel Commodore in New York, N. Y.

Other ASRE officers are:

Vice-president: A. B. Stickney, engineer, Armour and Company, Chicago, Ill.

Vice-president: John F. Stone, manager of the refrigeration division, Johns-Manville Corporation, New York, N. Y.

Treasurer: John G. Bergdoll, Jr., chief engineer, York Ice Machinery Corporation, York, Pa.

Directors elected by the ASRE to serve for a three-year period are:

Charles S. Leopold, consulting engineer, Philadelphia, Pa.; Lee G. Leslie, Johns-Manville Corporation, Philadelphia, Pa.; Nels Rosberg, production manager, California Consumers' Corporation, Los Angeles; Arthur B. Schellenberg, president of the Alco Valve Company, St. Louis, Mo.; J. Mack Tucker, University of Tennessee, Knoxville, Tenn.

AWS Announces New Officers

The American Welding Society has elected K. L. Hansen (F '34) consulting engineer, Harnischfeger Corporation, Milwaukee, Wis. (this issue, page 35), to serve as its president for the coming year. Other officers are as follows:

First vice-president: David Arnott, vice-president and chief surveyor, American Bureau of Ships, New York, N. Y.

Second vice-president: Isaac Harter, vice-president, The Babcock and Wilcox Company, Barberton, Ohio.

Directors-at-large: E. V. David, assistant manager, applied engineering department, Air Reduction Sales Company, New York, N. Y.; J. H. Critchett, vice-president, Union Carbide and Carbon Research Laboratories, Inc., New York, N. Y.; A. C. Weigel, vice-president, Combustion Engineering Company, New York, N. Y.; J. D. Gordon, general manager, Taylor-Winfield Corporation, Warren, Ohio.

Treasurer: O. B. J. Fraser, director of technical service, International Nickel Company, New York, N. Y.

District vice-president, New York–New England: E. R. Fish, chief engineer, boiler division, Hartford (Conn.) Steam Boiler Inspection and Insurance Company.

District vice-president, Middle Eastern: J. H. Humber-

stone, welding engineering department, Arcrods Corporation, Sparrows Point, Md.

District vice-president, Middle Western: J. D. Tebben, sales manager, Metallurgical Division, P. R. Mallory and Company, Indianapolis, Ind.

District vice-president, Southern District: K. B. Banks, assistant chief engineer, Black, Sivalls and Bryson, Oklahoma City, Okla.

District vice-president, Pacific Coast, P. D. McElfish, chief materials engineering, Los Angeles Division, Standard Oil Company of Calif., Los Angeles.

1943 Officers Elected by AIME

C. H. Mathewson, chairman of the department of metallurgy, Yale University, New Haven, Conn., recently was elected president of the American Institute of Mining and Metallurgical Engineers, New York, N. Y., for the year 1943.

Other officers elected are:

Vice-presidents: Erle V. Daveler, vice-president, Utah Copper Company, New York, N. Y.; Harvey S. Mudd, consulting engineer, Los Angeles, Calif.

Directors: H. J. Brown, consulting engineer, West Newton, Mass.; Charles H. Herty, Jr., assistant to vice-president, Bethlehem Steel Company, Bethlehem, Pa.; O. H. Johnson, vice-president, Mines and Smelter Supply Company, Denver, Colo.; Russell B. Paul, mining engineer, N. J. Zinc Company, New York, N. Y.; F. A. Wardlaw, Jr., assistant manager, International Smelting and Refining Company, Salt Lake City, Utah; Felix Edgar Wormser, secretary and treasurer, Lead Industries Association, New York, N. Y.

HONORS

Chemical Industry and Perkin Medals Awarded

The 1942 Chemical Industry Medal has been awarded to Harrison E. Howe, editor of *Industrial and Engineering Chemistry,* according to an announcement of the Society of Chemical Industry. Presentation of the medal awarded annually for valuable application of chemical research to industry, took place at a joint meeting of the American Section of the Society of Chemical Industry and the New York Section of the American Chemical Society.

The Society of Chemical Industry has announced also that the 1943 Perkin Medal, given annually for outstanding work in applied chemistry, has been awarded to Robert E. Wilson, president of the Pan American Petroleum and Transport Company, the American Oil Company, and other subsidiaries, was selected as the recipient of the medal by a committee representing the five chemical societies in the United States. Presentation will be made on January 8, 1943, at a joint meeting of the Society of Chemical Industry with the American Chemical Society, the American Institute of Chemical Engineers, the Electrochemical Society, and the Société de Chimie Industrielle.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without letter, the other lettered. Captions should be supplied for all illustrations.

A Suggestion for Saving Power—Series Versus Multiple Lighting

To the Editor:

Reference is made to a letter to the editor by L. Mackler (M '24) under the title of "A Suggestion for Saving Power," published on pages 543–4 of the October 1942 issue of *Electrical Engineering,* which revives the age-old argument of multiple street lighting systems versus series street lighting systems, with such strong apparent evidence as "this dreadful inefficiency exists only in series circuits."

It is necessary to view this letter with an open mind, since it has been demonstrated by actual practice in the public utility field during the past 25 years that there is a place for both types of street lighting systems in the economical distribution of street lighting and there are ample reasons to believe that there is an abundance of supporting data to prove that both types of street lighting systems are equally economical when properly engineered and operated. If anything the higher over-all efficiency is obtained with series street lighting circuits, when a faithful comparison is made.

In analyzing the series street lighting circuit losses indicated in this letter, it is difficult to understand how the 40–44 per cent losses would occur in the case of a series street lighting system only, assuming of course that this condition was existing during normal operation. Series street lighting normally carries 6.6 amperes and the wire size is generally number 6 or 8 American wire gauge. With this in mind it is believed that the circuit I^2R losses can be eliminated as the cause of the waste, since the loss would be very low per 1,000 feet of circuit. In this case we can proceed in the analysis to a comparison of series and multiple transformers. This immediately becomes an argument as to cost, since the efficiency of these transformers is approximately the same, roughly 96 per cent.

A series transformer is a current-regulating device, operating on the principle of magnetic induction, which when properly adjusted assures a long lamp life and uniform lighting intensity, by virtue of its current-regulating ability. A multiple transformer on the other hand is of a different design for the use of the principle of magnetic induction in that the current is permitted to increase in proportion to the load applied, within the kva rating of the transformer. In the case of the multiple transformer then, long lamp life and uniform lighting intensity are dependent upon good primary voltage regulation plus good inherent design. Good primary voltage regulation means costly plant equipment and careful maintenance; and good inherent design means regulation of at least $3^1/_2$ per cent. It is reasonable to assume then that the average regulation obtainable with multiple circuits, without an exorbitant outlay for primary regulation in excess of 5 per cent, would be approximately $7^1/_2$ per cent. This does not compare very favorably with 1 per cent current regulation obtainable with series transformers energized from an unregulated circuit.

The cost of $12.20 per kw for multiple transformers is acceptable if we neglect fixed charges, operation, and maintenance costs, but there is no reason why we must accept $96 per kw for series transformer capacity. The writer has designed a considerable number of series street lighting systems during the past 15 years and from the experience thus gained it is believed that $30 per kw for series transformer capacity would be ample when estimated on the same cost basis. Furthermore this figure would include the control equipment cost. It is pointed out that this figure is for overhead radial distribution systems. For underground circuits the figure for both multiple and series transformers would have to be increased.

In practice it has been proved that series street lighting systems are particularly advantageous in that contiguous distribution design is not seriously hampered by the street lighting load and a more economical distribution system results when the location of commercial and domestic transformers are not dependent upon the street lighting load. Series transformers have recorded extremely long service life in practice, which is due primarily to the fact that they are not affected seriously by overload and repeated short circuits. The opposite is true of all classes of multiple transformers since operating records obtainable indicate burnouts, from all causes, as high as $2^1/_2$ per cent of the transformers installed on overhead lines.

Going back to a comparison of the two types of circuits, it is pointed out that in the case of series circuits a single conductor loop of uniform wire size permits a large saving in copper over a multiple circuit in serving any unit of street lighting area. In addition a higher first cost as well as a higher maintenance and operating cost is required for multiple load relays when utilizing the distribution transformers on a multiple street lighting system.

It is believed that it would be well to look for reasons other than the electrical characteristics of the two types of circuits being compared in Mr. Mackler's letter, especially since such a wide margin has been recorded in losses and no convincing sup-

porting data have been advanced. Too, under wartime dim-outs and black-outs of street lighting it would be questionable saving indeed to revamp all series street lighting circuits at this time, even if it were economically feasible. But as for putting series circuits at the top of the list in the rationing of power, it is suggested that this part of power ration be given more engineering study before action is advised.

WILLIAM A. CROW

(Associate electrical engineer, War Department, Signal Corps, Red Bank, N. J.)

An A-C Bridge

To the Editor:

At the University of Kansas last summer I conceived the a-c bridge shown in Figure 1. The principle involved is very simple. If $R=\sqrt{\frac{L}{C}}$, arm 1–2 is resonant at all frequencies and has a purely resistive impedance equal to $\sqrt{\frac{L}{C}}$. The bridge is therefore balanced at all frequencies, including zero. The balance equation,

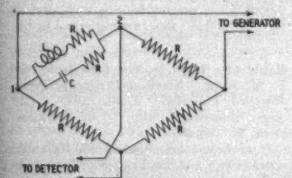


Figure 1

$L=CR^2$, can be used to compare inductances with capacitances.

Very little is known of the sensitivity of the circuit. Some rough measurements made at audio frequencies have indicated that the balance equation is approximately correct, and that harmonics in the generator are partially cancelled when the fundamental is balanced out.

BEN PETREE (Enrolled Student)

(University of Kansas, Lawrence)

Terminal Corrections for Temperature Tests on Short Conductors

To the Editor:

In an interesting letter by Frederick Bauer and Jerome J. Taylor, entitled "Terminal Corrections for Temperature Tests on Short Samples," published in the November issue of *Electrical Engineering*, pages 584–5, methods are given for computing the cooling effect produced by terminals upon the temperature of conductors connected to them.

The method given is entirely correct for conductors which are of infinite length or for conductors sufficiently long, as is the case in the example given, that the cooling effect of the terminal has a negligible effect upon the temperature at or near the center. It is, however, not correct for thermally short conductors, as will be shown.

In my paper, "The Compensated Thermocouple Ammeter," published in AIEE *Transactions*, volume 55, 1936, January section, pages 22–33, the problems given in the letter referred to were treated in general. The paper on thermocouple ammeters might more appropriately have been entitled, "The Temperatures Along a Conductor to Which Heat Is Added or Removed Uniformly Throughout Its Length, Connected to Terminals, and Mounted in a Cooling (or Heating) Medium."

In the paper on thermocouple ammeters equation 5

$$\theta=\theta_0-\left[\frac{(\theta_0-T_1)\sinh(L-x)n+(\theta_0-T_2)\sinh xn}{\sinh Ln}\right]$$

is the general equation for the temperature θ at any point at a distance x along a conductor of any length L, from a terminal at temperature T_1 to a terminal at temperature T_2 at a distance $x=L$. All temperatures are relative to that of the surrounding medium.

In this equation

$$n=\sqrt{\frac{c}{ak}}$$

is the thermal length of the conductor per unit length in hyperbolic radians in which c is the heat lost to the surrounding air per unit length of conductor per degree;

a is the cross-sectional area of the conductor and k its thermal conductivity.

In this equation the value of n, c, and $1/ak$ correspond respectively to α, h, and r in the equation of Messrs. Bauer and Taylor for α.

In connection with the latter equation, attention is called to a typographical error which might cause confusion, namely, r should be the thermal resistance and not resistivity.

In the general equation θ_0 is the temperature, relative to the surrounding air, the conductor would have if no heat were lost to the terminals, and it is the temperature above ambient at the center of a conductor so long, thermally, that this temperature is not affected by the terminals. The temperature θ_0 added to the ambient temperature corresponds to the temperature at the center of the long conductor referred to in the letter of Messrs. Bauer and Taylor.

If in this equation L is made infinite, the equation reduces to,

$$\theta=\theta_0-[(\theta_0-T_1)e^{-nx}]$$

which is the same as that given in the letter of Messrs. Bauer and Taylor.

This equation may be modified to bring out its physical meaning more clearly by putting the difference in temperature between any point x and the terminal, in terms of the difference in temperature between the center and the terminal, by subtracting from each side the temperature T of the terminals assumed equal, we then have $(\theta-T)=(\theta_0-T)(1-e^{-nx})$. If we employ this equation, which is correct for thermally long conductors only, for thermally short conductors and assume that θ_0 for the center of a long conductor can be used equally well for short conductors having at emperature of θ_c at the center, then the equation, although incorrect, would be $(\theta-T)=(\theta_c-T)(1-e^{-nx})$.

To show that this is incorrect for short conductors, assume that the length is 2 feet instead of 30 feet as given in the example of Messrs. Bauer and Taylor, then, using their constants,

$$(\theta-T)=(\theta_c-T)(1-e^{-0.138\times 15})$$

or

$$(\theta-T)=(\theta_c-T)(1-0.2)=(\theta_c-T)\times 0.8$$

that is, the computed temperature of the center above that of the terminal is 20 per cent less than the measured value, and other parts of the conductor will have corresponding errors.

For the 30-foot conductor used in the example the corresponding ratio would be,

$$(1-e^{-0.138\times 150})=0.9999993$$

which shows the great difference between computed values for long and short conductors.

The correct equation in general for the temperature at any part of a conductor of any length, in terms of the measured value at the center when the two terminals have the same temperature T, is obtained from the general equation given previously by first determining the temperature θ_c at the center by making $x=L/2$, and then eliminating θ_0, from which we obtain,

$$(\theta-T)=\frac{(\theta_c-T)}{\left(1-\frac{1}{\cosh\frac{Ln}{2}}\right)}\times\left[1-\frac{\sinh(L-x)n+\sinh xn}{\sinh Ln}\right]$$

W. N. GOODWIN, JR. (F '13)

(Chief engineer, Weston Electrical Instrument Corporation, Newark, N. J.)

Railway Electrification

To the Editor:

A recent issue of the *Railway Gazette* of London indicates that as of March 1, 1942, the last of the electrification between Jörn and Boden in Sweden gives the Swedish State Railways the distinction of owning the longest continuous railway electrification in the world, from Riksgränsen to Talleborg. This distance is 1,349 miles and if the Norwegian section between Riksgränsen and Narvik be added, the total electrification is 1,376 miles.

It is pointed out that the German electrification from Saalfeld through Munich and the Brenner Pass, and the Italian electrification from Brennero through Verano to Reggio constitutes a continuous electrification of 1,268 miles, 366 miles of which is in Germany and 902 miles in Italy. There is thus continuous electric operation from the Arctic Circle to the Mediterranean Sea (with the exception of the Baltic Sea crossing the section between the Baltic and Saalfeld) totalling 2,644 miles.

Four systems of power distribution are used, the Swedish and German railroads being single phase at 16,000 and 15,000 volts respectively, and the Italian railroads being three phase at 3,700 volts and direct current at 3,000 volts.

It is interesting to note the extent of electric operation in view of the complications in construction and operation incident to the war.

SIDNEY WITHINGTON (F '24)

(Electrical engineer, The New York, New Haven, and Hartford Railroad Company, New Haven, Conn.)

NEW BOOKS • • •

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

X-Ray Crystallography. By M. J. Buerger. John Wiley and Sons, New York; Chapman and Hall, London, 1942. 531 pages, illustrations, etc., 9½ by 6 inches, cloth, $6.50. (ESL).

Intended to provide a connected account of the theory and practice of structural investigations by means of the X-ray. Methods that utilize a single crystal and monochromatic X-rays and the theory necessary for the intelligent use of these methods are discussed. Much of the material appears in print for the first time.

Plastics. By J. H. DuBois. American Technical Society, Chicago, Ill., 1942. 295 pages, illustrations, etc., 8½ by 5½ inches, cloth, $3. (ESL).

Written for users of plastics who wish practical information concerning these materials, this book outlines the history and origin of the various types of plastics and the sources of their raw materials. Their physical, chemical, and electrical properties are discussed, as well as their advantages and defects. Due attention is paid to their fabrication, and information on design is presented.

Molecular Films, the Cyclotron and the New Biology. By H. S. Taylor, E. O. Lawrence, I. Langmuir. Rutgers University Press, New Brunswick, N. J., 1942. 95 pages, illustrations, etc., 9½ by 6 inches, cloth, $1.25. (ESL).

These essays by three distinguished scientists present historical and contemporary concepts that will help to solve some of the most difficult problems in biology. Dr. Taylor provides the historical background with a review of scientific thought during the last two centuries. Dr. Lawrence describes the cyclotron and calls attention to its promise as a means for studying biological problems. Dr. Langmuir presents the surface-film method of investigation, describes some results obtained and suggests further uses.

American Electricians' Handbook. By T. Croft, revised by C. C. Carr. 5th edition. McGraw-Hill Book Company, New York, N. Y., and London, England, 1942. 1,634 pages, illustrations, etc., 8 by 5 inches, $5. (ESL).

The new edition of this well-known reference book has been thoroughly revised and considerably expanded, new sections on the properties and splicing of conductors and on general electric equipment and batteries have been added, and others have been rearranged. The book aims to meet the needs of those having little technical training by providing accurate information, based on correct engineering principles, in simple language.

New Technical and Commercial Dictionary. Part I, Spanish–English; Part II, English–Spanish; Part III, Conversion Tables of Weights, Measures, and Monetary Units. Compiled by A. P. Guerrero. Editorial Técnica Unida and Chemical Publishing Company, Brooklyn, N. Y. 1942. 600 pages, tables, 9½ by 6 inches, fabrikoid, $10. (ESL).

This dictionary contains more than 50,000 words used in electrical, mechanical, chemical and marine engineering, radio, mining, textile, and other industries. It includes modern words referring to mechanized and motorized warfare, aviation, meteorology, and other technical fields.

Poisson's Exponential Binomial Limits. Table I—Individual Terms; Table II—Cumulated Terms. By E. C. Molina. D. Van Nostrand Company, New York, N. Y., 1942. 47 pages, tables, 11 by 8 inches, paper, $2.75. (ESL).

These tables give the numerical limiting values of the individual and cumulative terms for values of the parameter from 0.001 to 100. Originally prepared by the Bell Telephone System for use in solving switching and traffic problems, they are also very useful in handling inspection data and solving problems of sampling.

Powder Metallurgy. Edited by J. Wulff. American Society for Metals, Cleveland, Ohio, 1942. 622 pages, illustrations, etc., 9½ by 6 inches, $7.50. (ESL).

Contains papers presented at conferences held in 1940 and 1941 at the Massachusetts Institute of Technology, Cambridge. Various problems connected with the preparation and use of metal powder are discussed by specialists, and a large amount of information is presented in convenient form. Most chapters have bibliographies.

Procedure Handbook of Arc Welding Design and Practice. 7th edition. Lincoln Electric Company, Cleveland, Ohio, 1942. 1,267 pages, illustrations, etc., 9 by 6 inches, fabrikoid, $1.50 in U.S.A.; $2 elsewhere. (ESL).

This reference book attempts to present a comprehensive, authoritative description of the arc-welding process. Methods and equipment, welding technique, procedures, speeds, costs, test methods, design of welded machines and structures, and typical applications of welding are considered. The new edition has been revised and enlarged.

Tables of Probability Functions. Volume 2. Prepared by the Federal Works Agency, Work Projects Administration for the City of New York, N. Y., conducted under the sponsorship of and for sale by the National Bureau of Standards, Washington, D. C., 1942. 344 pages, tables, 11 by 8 inches, cloth, $2. (ESL).

The two functions tabulated here are frequently called the ordinate and area respectively of the normal frequency curve, and are of fundamental importance in statistics, especially in testing the significance of a deviation in a normally distributed variate and in fitting normal distributions to observations. The tables extend to 15 decimal places, at intervals of 0.0001 for x ranging from 0 to 1, and at intervals of 0.001 for x ranging from 1 to 7.8.

Cable Car Days in San Francisco. By E. M. Kahn. Stanford University Press, Stanford University, Calif., 1941. 124 pages, illustrations, etc., 10 by 7 inches, cloth, $3. (ESL).

A pleasant, informal account of the cable street railways of San Francisco, from their beginnings down to the present time. Photographs and drawings add to the attractiveness of the text.

PAMPHLETS • • •

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Tin—Base Bearing Metals (publication number III). By W. T. Pell-Walpole, J. C. Prytherch, Bruce Chalmers. Battelle Memorial Institute, Columbus, Ohio; Tin Research Institute, Fraser Road, Greenford, Middlesex, England, 1942. 38 pages, no charge for single copies.

The Specific Heats of Certain Gases Over Wide Ranges of Pressures and Temperatures. By Frank O. Ellenwood, Nicholas Kulik, Norman Gay, Cornell University Engineering Experiment Station, Ithaca, N. Y., 1942. 22 pages, no charge for single copies (additional copies 50 cents).

The Future of Transportation. National Resources Planning Board, Washington, D. C., 1942. 43 pages.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Any discussion of these papers will appear in the June 1943 Supplement to Electrical Engineering—Transactions Section

Performance Calculations on Tapped-Winding Capacitor Motors

A Method of Calculating Low-Speed Performance of Two-Speed Capacitor Motors With Open-End Type of Control Winding

P. H. TRICKEY
MEMBER AIEE

THE tapped-winding capacitor motor is used quite commonly to obtain a two-speed fan motor with a comparatively simple switching arrangement. With the open-end type of connection as shown in Figure 1, the high-speed connection gives a normal capacitor motor, and its performance under any load may be determined by calculation with the formulas of either the revolving-field theory or the cross-field theory. When a control winding is added to the already complicated capacitor motor circuits, the analysis by the usual methods becomes even more difficult, and the calculation more involved and tedious than ever. In the following discussion a method is presented for calculating the low-speed performance. This method while not absolutely rigorous, should give results well within the limits of variation of individual motors of the same design.

Analyzing the Problem

The problem may be divided into two parts:

1. The performance of the motor is obtained when operating with the high-speed connection at the lower than normal voltage which will give the desired second speed.

2. If one knows the performance at the proper speed with a certain line voltage applied, the voltage is calculated which will be necessary to apply to the total main and control winding to give the same speed. If this voltage is not equal to the line voltage, a different control winding must be designed.

Paper 43-4, recommended by the AIEE committee on electrical machinery for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted June 4, 1942; made available for printing October 20, 1942.

P. H. TRICKEY is chief engineer, Diehl Manufacturing Company, Elizabethport, N. J.

Low-Speed Performance on High-Speed Connection

One procedure to obtain the low-voltage performance would be to calculate the full-voltage performance at the desired second speed such as point *B* in Figure 4. Then if one knows that the fan torque of point *A* varies as the square of the speed and that the motor torque of point *B* varies as the square of the voltage, the proper voltage to use in calculating point could be obtained by simple ratios.

In actual practice, however, this procedure does not always work out so perfectly, partly because of the change in saturation factor with lower voltage, but mainly because the friction does not drop off with voltage, the torque which should equal point *C* very often is a little more or less, and a third calculation must be made. It has been found advantageous to estimate the voltage for point *C* with its corresponding saturation factor. It is usually found that the torque is so close to point *C* that in one more trial the performance at point *C* is determined, and thus the result is obtained in two trials instead of three.

Another and sometimes more convenient method to obtain the low-voltage low-speed performance is by actual test. The common fan-load test with variable voltage known as the fan saturation test gives the performance of the motor and blade at various voltages and speeds. It makes no difference to the second part of this problem whether the low-voltage low-speed values are obtained from test or calculation. In fact, the calculation sheet shown in Figure 3 shows an approximate method for use when the test does not have phase readings.

Low-Speed Performance on Low-Speed Connection

With the low-voltage performance as a foundation, it is now possible to calculate the performance on the low-speed connection at the same rpm. With the speed set, the voltage necessary to drive the fan at this speed is calculated, and the current and input are obtained. If this voltage

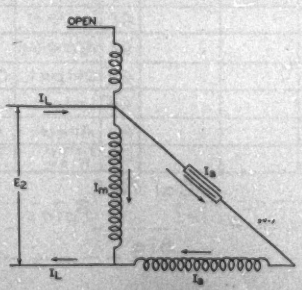


Figure 1. Low-voltage operation on high-speed connection

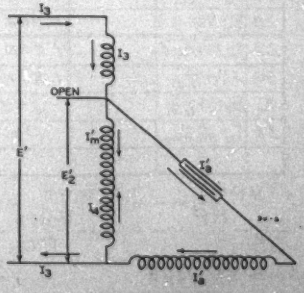
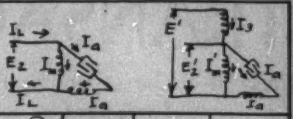


Figure 2. Full-voltage operation on low-speed connection

Calculation Sheet for Tapped Winding Capacitor Motors

CK_{wm}	795	CK_{w3}	468			C_3	1.3	
r_{im} hot	5.24	$K_3=\frac{CK_{w3}}{CK_{wm}}$	.589			t.p.c.	45	
r_{ia} hot	24.7	$K_3'=K_3+1$	1.589			Wire Size	#23	
X_m	10.5	r_3 hot	5.57					
$X_{im}=X_m\sqrt{1+K_3}$	5.43	$x_3=X_mK_3^2C_3$	4.72					



	Exact	Approx.	Exact	Approx.		33	$e_{2h}=(14)$	$E_2=①$	43.15	60.0	
1	Low Voltage E_2	E_2	60	60		34	(25) r_{im}		5.20		
2	W_L	W_L	120	120		35	-(26) x_{im}		5.35		
3	I_L	I_L	2.33	2.33		36	$E_{2h}'=(33)+(35)$		53.70		
4	A_L	A_L	2.00	2.00		37	$e_{3h}=(34)K_3$	(19)	25.4	25.4	
5	B_L	B_L	-1.20	-1.20		38	(30) r_3	(21) r_3	7.15	8.2	
6	W_m		104.5			39	-(31) X_3		3.68		
7	I_m		2.25			40	$E_h'=(34)+(39)$		89.9		
8	A_m		1.74			41	$e_{2v}=(17)$		-1.99		
9	B_m		-1.426			42	(28) r_{im}		-5.15		
10	$A_m r_{im}$	$A_L r_{im}$	9.11	10.47		43	(41)+(42)		-7.14		
11	$-B_m x_{im}$	$-B_L x_{im}$	7.74	6.52		44	(25) x_{im}		+5.40		
12	$E_2=①$	$E_2=①$	60.0	6.00		45	$E_2'=(43)+(44)$		-1.74		
13	⑩+⑪	⑩+⑪	16.85	16.99		46	$e_3=(41)K_3$		-1.172		
14	$e_{2h}=⑫-⑬$		43.15			47	(31) r_3		-4.22		
15	$-B_m r_{im}$		7.47			48	(45) to (47)		-7.132		
16	$A_m x_{im}$		9.46			49	(30) X_3		5.96		
17	$e_{2v}=⑮-⑯$		-1.99			50	$E_v'=(48)+(49)$		-1.172		
18	$e_2=\sqrt{⑭^2+⑰^2}$	$e_2=⑫-⑬$	43.2	43.01		51	$E_2'=\sqrt{(48)^2+(50)^2}$	$E_2'=\sqrt{(33)^2+(38)^2}$	89.9	93.6	
19	$e_3=K_3e_2$	$e_3=K_3e_2$	25.4	25.4		52	$E_2'=\sqrt{(34)^2+(40)^2}$		53.7		
20	$I_L=③$	$I_L=③$	2.33	2.33		53	$I_a'=(32)\frac{(52)}{(1)}$		3.22		
21	$I_3=I_L/K_3'$	$I_3=I_L/K_3'$	1.47	1.47		54	$W_L=(2)$	(2)	120	120	
22	$I_4=I_L\ I_3$		.86			55	$(21)^2\ r_3$		12.1		
23	$A_m=⑧$		1.74			56	$(29)^2\ r_{im}$		10.2		
24	$A_4=⑧\frac{(22)}{(20)}$		.747			57	$(53)^2 r_{ia}$		2.56		
25	$A_m'=(23)-(24)$		.993			58	(54) to (57)		144.86		
26	$B_m=⑨$		-1.426			59	$(7)^2 r_{im}$		26.5		
27	$B_4=(5)\frac{(22)}{(20)}$		-.443			60	$(32)^2 r_{ia}$		3.2		
28	$B_m'=(26)-(27)$		-.983			61	(59)+(60)		29.7		
29	$I_m'=\sqrt{(25)^2+(28)^2}$		1.398			62	$W_3=(58)-(61)$	(2)	115.2	120	
30	$A_3=(1)\frac{(21)}{(20)}$		1.261			63	Output	Output			
31	$B_3=(5)\frac{(21)}{(20)}$		-.757			64	Losses	Losses			
32	$I_a=$ Aux. Ph. Amps		.36			65	Area	Area			
						66	Temp. Rise	Temp. Rise			

Type____ Frame_____ Cal. Ref._____ Duty_____

___ HP_____ Volts____ Cycles____ Poles_____ RPM Date__/__

SS_____ F.O._____ Sig._____ ES_____

Form EN 1769 Wdg._____

Figure 3. Example calculation

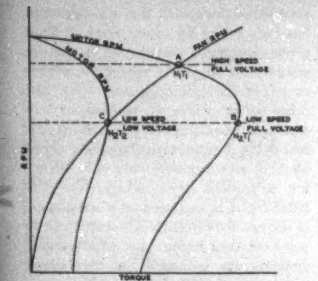


Figure 4. Motor and fan speed-torque curves

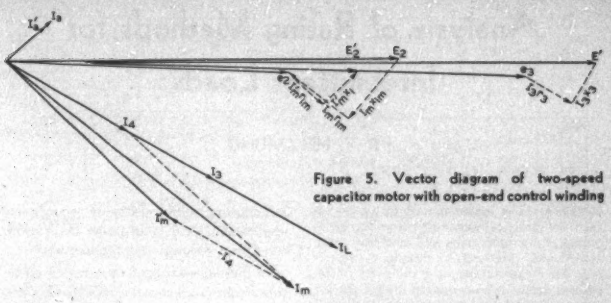


Figure 5. Vector diagram of two-speed capacitor motor with open-end control winding

E' is not equal to the line voltage, the motor will not drive the fan at the proper second speed, and a new control winding must be designed.

Figure 5 shows the combined vector diagrams of the two connections when operating at the same speed. I_m, I_a, and I_L are the currents with the high-speed connection and low-voltage E_2. The induced voltage e_3 in the main winding is obtained by subtracting the reactance and resistance drops in the main winding due to the current I_m. It is assumed that this induced voltage will remain the same under the low-speed connection if the speed is maintained at the same value.

Since the control winding is placed in the main-winding slots, it acts with the main winding to form an autotransformer as well as to provide a series impedance. It is assumed that the autotransformer and motor effects are superimposed on each and that the motor provides the magnetizing current. Because of the transformer action, the new line amperes I_3 will be reduced from I_L in the transformer ratio.

$$I_3 = I_L / K_3'$$

where

$K_3' = K_3 + 1$

$K_3 = CK_{wa} / CK_{wm}$

CK_{wa} = effective series conductors in control winding

CK_{wm} = effective series conductors in main winding

Because of the transformer action, the main winding carries a transformer current

$$I_4 = I_L - I_3$$

The actual current in the main winding I_m' will be a combination of this current I_4 with the main-winding motor current I_m.

$$I_m' = I_m - I_4$$

When all the new current values in each branch of the circuit are obtained, the new low-speed connection line voltage E' may be obtained by adding to e_2 the proper impedance drops plus the induced voltage e_3 in the control winding.

$$E' = e_2 + I_m' r_{1m} + jI_m' x_{1m} + e_3 + I_3 r_3 + jI_3 x_3$$

$$e_3 = K_3 e_2$$

The input will differ somewhat from W_L, the input on the high-speed connection, by the addition of the control winding copper loss $I_3^2 r_3$, and by the reduction in the copper loss in the other two windings. The main-winding copper loss is reduced because of the lower value of the current I_m'. Also due to this reduced main-winding current, the capacitor-phase terminal voltage E_2' is less than E_2, and with it the capacitor-phase current I_a'. The capacitor-phase copper loss is reduced accordingly.

Figure 3 shows a convenient form of calculation sheet with an illustrative example.

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1. The Revolving-Field Theory of the Capacitor Motor, W. J. Morrill. AIEE Transactions, volume 48, 1929, page 614.

2. The Apparent-Impedance Method of Calculating Single-Phase Motor Performance, W. J. Morrill. AIEE Transactions, volume 60, 1941, December section, page 1037.

3. Performance Calculations on Capacitor Motors, P. H. Trickey. AIEE Transactions, volume 60, 1941, February section, page 73.

4. The Design of Capacitor Motors for Balanced Operation, P. H. Trickey. AIEE Transactions, volume 51, 1932, page 780.

5. The Equal-Volt-Ampere Method of Designing Capacitor Motors, P. H. Trickey. AIEE Transactions, volume 60, 1941, November section, page 990.

6. The Cross-Field Theory of the Capacitor Motor, A. F. Puchstein, T. C. Lloyd. AIEE Transactions, volume 60, 1941, February section, page 58.

Analysis of Rating Methods for Intermittent Loads

R. E. HELLMUND
FELLOW AIEE (Deceased)

Synopsis: The economics of rating structures for electrical equipment from the viewpoints of manufacturing and application are considered. Methods for dealing with periodic load applications are reviewed. The present methods have certain limitations for some practical applications. An improved method for applying motors to load cycles where the motor stops and ventilation changes in the no-load part of the cycle is developed. This method is based on certain motor-loss ratios, that is, the relation between the losses dissipated with standard temperature rise running and at standstill and the losses at the nominal or short-time rating. It permits the application of service-factor or short-time ratings to periodic loads with more exactness. Attention is called to the wide variations in permissible rms current on periodic loads for different loss ratios and changes in ventilation on a motor.

Rating Structures

RATINGS for intermittent or varying loads have recently received considerable attention[4–10] and AIEE Standard 1*A*[1] is an attempt to clarify and rationalize suitable methods for this purpose. No radically new methods of rating are proposed, but some new nomenclature and new viewpoints are introduced; the report also advocates increased use of some methods of rating which in the past have been applied to only a limited extent.

Naturally there is some hesitation in making changes in the rating practice, which is justified, because departures from well-established methods are likely to lead to confusion and expense. On the other hand, it must be realized that any change in practice which results in economies appreciably outweighing the disadvantages involved will probably be made sooner or later. All action of this nature should be based primarily on economic considerations. Broadly speaking, the number of rating methods should be kept as small as possible but they should not be so limited that they prevent satisfactory and reasonably economical applications of devices under the various conditions encountered in practice.

In making changes in the rating structure from an economic point of view, serious thought should be given to what such a change really entails. If a new rating method requires entirely new lines of machines and apparatus different from those already in existence and thus interferes with quantity production, and if it furthermore complicates the stock situation both at the factory and in the field, it is justified only if it leads to decided improvements. On the other hand, if a change merely means giving some additional data for apparatus already standardized, it should not be objectionable. Even here it must be realized that the additional information means expense and complications in listing, merchandising, and applying the apparatus. Hence the inclination to adhere to the present practice of handling most apparatus by means of a single continuous rating as far as possible is quite natural. In the past, a departure from this simple practice has in general been made only under compelling circumstances. An example of an extreme case is the rating and application of single-phase railway motors[2] where the information given with the rating structure entails weeks of expensive tests as well as time-consuming methods of application. These expenses, however, are unquestionably well justified in view of the large number of motors of the same rating in use and the enormous investment involved. Between the extreme conditions there is, of course, room for a variety of intermediate practices, some of which have been used to a limited extent, as, for example, the rating structure for d-c railway, mill-type, and other motors. In deciding whether the use of a more complicated rating structure is warranted, the expense for securing and giving additional rating data as well as the advantages derived should be taken into account. Frequently the inclusion of additional information will result in easy and economical application and fully compensate for the expense involved. The choice of method should also be influenced by the existence or lack of well-established practices. If a rating practice has been in use for many years and has given reasonable satisfaction, a change would seem advisable only if the advantages obtained are appreciable. On the other hand, where it is necessary to establish new rating structures in entirely new fields, it seems logical to apply newer methods although they have only moderate advantage over others. In the following it is proposed to discuss some of the methods recently advocated and to point out their limitations; subsequently methods are indicated for overcoming these limitations and for handling cases which do not seem to be covered satisfactorily by AIEE Standard 1*A* and related literature.

Paper 43-6, recommended by the AIEE committee on electrical machinery and the standards co-ordinating committee 4 for presentation at the AIEE national technical meeting, New York, N. Y., January 25–29, 1943. Manuscript submitted September 23, 1942; made available for printing November 2, 1942.

R. E. HELLMUND was chief engineer of Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., at the time of his death, May 1942.

Ratings for Intermittent Duty

AIEE Standard 1*A* strongly emphasizes the many applications of electrical machines and apparatus where a given load is carried for sustained periods or repeatedly for shorter periods, but where there are also light- or no-load conditions. The device must be satisfactory for the required load in many respects, such as regulation, torque characteristics, mechanical strength, and so forth, and it is therefore proposed to assign a nominal rating corresponding to the load. It is also proposed to take advantage in the design of the noncontinuous nature of the load.

Two methods are given for such cases, namely, the dual or service-factor method and the load-cycle method of rating. In the first method the nominal rating is supplemented by a service factor, which is the ratio of the continuous rating to the nominal rating and thus indicates the continuous rms rating of the machine or apparatus. This method, when applicable, has the advantage of being much more flexible in application than the load-cycle method. It permits the analysis of loads of varying size and time of application, merely requiring that the rms load does not exceed the continuous load indicated by the service factor. In contrast, the load-cycle method is rather inflexible in its present form as its application is limited to a single load cycle, with both the amplitude and duration of the load for each cycle specified. Therefore, this method naturally will be considered only where for some reason the service-factor method is not suitable.

Either of the periodic rating methods permits designs smaller than those with continuous ratings equal to the proposed nominal ratings of the periodic rating methods. Thus appreciable economy

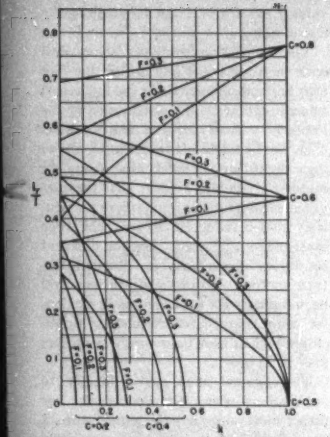

Figure 1. Curves for equation 3 of Appendix I, with loss ratios C and F variable and $p = 0.5$, showing permissible rms currents for different ratios of running time per cycle

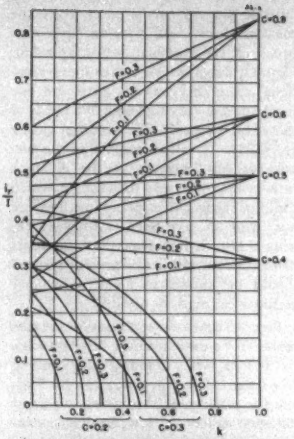

Figure 2. Curves for equation 3 of Appendix I, with loss ratios C and F variable and $p = 0.333$, showing permissible rms currents for different ratios of running time per cycle

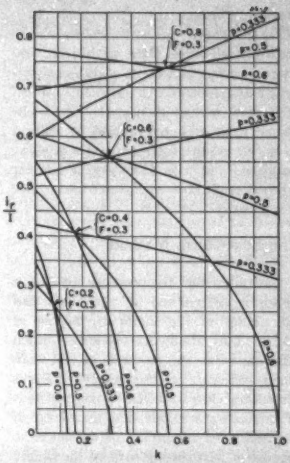

Figure 3. Curves for equation 3 of Appendix I, with loss ratios p and C variable and $F = 0.3$, showing permissible rms currents for different ratios of running time per cycle

may be accomplished in view of the many applications where continuous loads are not involved. However, it is highly desirable to obtain this economy without creating entirely new lines of ratings. This can be done by using the standard short-time ratings[8,9] wherever they exist. These ratings cannot carry the nominal rated load continuously but usually are suitable for service-factor or load-cycle ratings. To get a service-factor rating, or to indicate the load duration and the percentage of the total time during which the nominal load can be carried to obtain a load-cycle rating, it is then merely necessary to supplement the short-time or nominal rating with the service factor. Even where no short-time ratings are available and new ratings have to be established, it seems desirable to make designs which are suitable for two or more of the rating methods, such as short-time, service-factor, and load-cycle ratings.

Unfortunately the service-factor method, which is flexible in its application to a great variety of load conditions, is not always applicable. It is based on a single rms value applying for a constant condition of cooling, which results in limitations under certain conditions.

For example, when a device cannot carry any load continuously without overheating, it is obviously impossible to give a service factor. This is frequently the case with enclosed machines or other enclosed apparatus where the core and similar losses, if prevailing continuously, cause temperature rises in excess of those permissible for continuous operation. Such devices can be and frequently are used to good advantage on intermittent loads where no core or similar losses occur during idle periods. (In a few cases, such as series d-c motors where the speed varies and the operating voltage ranges between zero and rated voltage, an rms rating can at times be given at a reduced voltage corresponding to the average operating voltage and a modified application of the service-factor method is possible.)

Again, when the ventilation during the on and off periods of a load cycle changes materially, making the resultant effective ventilation appreciably less than the ventilation prevailing during the tests with the continuous load current, the service-factor method cannot be readily applied. Motors which stand still during the no-load periods, with an appreciable reduction in ventilation, are an illustration of this.

When the heating or other operating limitations of devices are not entirely a function of the rms current, the service-factor method is not very suitable. For example, in electronic tubes the safe output is influenced by many different factors but only to a negligible extent by the rms load, and therefore the rms load cannot be used as a correct indicator of permissible load.

In these cases and possibly others, the load-cycle method of rating may have to be considered, and it would be of advantage to find ways of making this method more flexible. One possible way is to assign to a given device, in place of a single load-cycle rating, a number of different load-cycle ratings[9,10] in such a way that intermediate applications can be handled by interpolation. This method has been used with electronic devices for applications, such as spot welding, and is giving satisfactory results in practice. Although the assignment of a number of ratings naturally introduces complications, in this case the necessary interpolation can be readily and quickly made and, in fact, takes less time than the calculation of the rms or average currents. In other words, the extra expense for establishing several ratings is compensated for by time saved in applying the device.

Periodic Loads on Motors

Unfortunately, a similar practice for motors is almost out of the question. An acceptance test for a load cycle during which the motor must be started and stopped repeatedly is difficult because of temperature measurement and the necessity of properly adjusting the load to the desired value during each cycle. Fair results can be obtained where the operating period is reasonably long, but serious difficulties are encountered in short load cycles, which are more common in practice. Therefore an entirely different

method of attack seems desirable. In a previous paper[7], a method permitting certain load-cycle tests with relatively long operating periods on standard short-time rating motors was outlined. Methods were indicated whereby data obtained from such tests could be utilized to derive results for load cycles of short duration. In the following a simpler method applicable with short load cycles is suggested.

The Loss-Ratio Method

Basically, the temperature rise of a motor is determined by the losses and the ability of the motor to dispose of them. This ability is obviously much different when the motor is at rest than when running. Consequently it seems almost hopeless to devise proper methods of application without some knowledge of the losses and the ability of the motor to dispose of heat during each of the widely different conditions of operation. Furthermore, with this knowledge, applications can be readily made for any motor having a short-time or any other nominal rating. The essential quantities are:

1. The constant losses (core and so forth) at the nominal rating $= L_c$
2. The variable losses (copper and so forth) at the nominal rating $= L_v$
3. The continuous losses permissible for standard temperature rise[1] at rated speed $= L_r$
4. The continuous losses permissible for standard temperature rise at standstill $= L_s$

Values for the first two items are always available from the efficiency determination of the machine. With a service-factor rating, the value for the third item can be readily calculated from items 1 and 2 by use of the service factor (equation 4, Appendix I). If no service-factor rating is available, the information for item 3 can be obtained from a continuous run at reduced voltage and load giving standard temperature rise. Preferably the ratio between constant and varying losses during this test should be the same as at the nominal rating. The information for the fourth item can be obtained by a continuous test run with the motor at rest, at a voltage low enough to again result in the standard temperature rise. Then by means of the simple algebra of Appendix I, any desired load-cycle condition can be calculated. Formula 2 gives the load current which can be carried for any value of running time per cycle, and formula 3 indicates the rms current for the entire load cycle corresponding to the load current of formula 2. Figure 1 shows curves indicating the value of the permissible rms current for cases where the constant losses and varying losses are equal at the nominal rating ($p=0.5$). Figure 2 shows similar curves for applications where the constant losses are one third and the varying losses two thirds of the total losses at the nominal rating ($p=0.33$). It will be noted that the permissible rms current for the different ratios varies over very wide ranges, which confirms the fact that inexact methods are not likely to give very satisfactory results. Also, it is evident that the basic factors considered in the present method should be known to make reasonably accurate calculations possible.

Figure 3 again shows values for the rms current for a constant ratio of permissible continuous losses standing and running ($F=0.3$). Different ratios (p) for constant to total losses at nominal rating and different ratios (C) for permissible continuous losses running to total losses at the nominal rating are used. A number of curves of this character, each for a different value of F, seem to be most suitable for practical use. The ratio F is a machine characteristic, whereas p and C depend upon the nominal rating considered. Reasonably correct results can be obtained from such curves by interpolation for different values of the various ratios. Since the variables used in this method are all ratios of losses, this method might be referred to as the "loss-ratio method." It is applicable directly to existing short-time ratings as well as to service-factor ratings, and it therefore obviates the necessity for separate and distinct lines of additional ratings.

In a previous paper[8] dealing with load-cycle ratings, a factor (S_3) was introduced to cover motors standing still during no-load periods. The formulas given were based on a factor (f), intended to make allowance for reduced ventilation and the absence of core losses at standstill. These two effects influence results in opposite directions, and thus factor f depends upon the difference of two quantities. Since in practice each of these effects varies over wide ranges, the resultant difference is erratic, making it almost impossible to deal with uniformly consistent values for f (see discussion of paper, reference 8). Formula 5 of Appendix I gives the same factor (S_3) in terms of the loss ratio F. With the method now proposed, factor F depends only upon the change of ventilating conditions and hence is likely to be fairly uniform, or at least quite consistent for a given type and line of machines. Therefore the present method will yield reasonably correct results even if test data for the value F are not available for all sizes of a line of motors.

The calculations outlined above deal with the total losses and neglect the fact that hot-spot temperatures are influenced to some extent by the distribution of the losses in various parts of the machine. This can be taken into account by allowing a slight factor of safety in applying the motors. It is also evident that the previous considerations apply more particularly to a-c induction motors, the type most universally used. For the different conditions prevailing in commutator-type motors, certain modifications will be necessary; for series motors in particular, more complicated methods of application such as used for d-c railway motors may be in order.

These calculations apply directly to applications where the load cycles are rather short and where the temperature of the machine does not vary materially during the cycle, the applications most common in practice. For relatively long load cycles or for load cycles very unevenly distributed, the methods previously outlined[8] for the service-factor method can be used, or the factor S_3 given there can be applied to the method outlined here. In other words, the factor S_3 can be used to give the relations between short- and long-cycle applications regardless of whether the service-factor rating is given. When no service factor is given, the permissible rms current is obtained from formula 3, Appendix I, for short-load cycles. By multiplying this value by the factor S_3 (Figure 7 of reference 8), permissible rms values for longer load cycles involving appreciable temperature changes can be obtained. Thus the loss-ratio method is applicable to both types of periodic duty cycles involving standstill during the no-load period, a condition for which other methods have limitations.

Appendix I. Determination of Permissible Periodic Load Cycles for Motors by the Loss-Ratio Method

Let

L = total losses at the nominal rating current I

L_c = constant (core and so forth) losses $= pL$

L_v = variable (copper and so forth) losses $= (1-p)L$

L_r = continuous losses at rated speed for standard temperature rise

L_s = continuous losses at standstill for standard temperature rise

$L_r = CL$ where $C = L_r/L$
$L_s = FL_r = CFL$ where $F = L_s/L_r$
T = total time per cycle
$T_r = kT$ = running time per cycle

For any value of k, the losses which can be dissipated during the total cycle must equal the losses produced by a certain load current (i_k) during the running part of the cycle.

Therefore

$$L_r k + L_s(1-k) = L_c k + \left(\frac{i_k}{I}\right)^2 L_s k \qquad (1)$$

Introducing the loss ratios p, C, and F and solving

$$i_k = I\sqrt{\frac{1}{1-p}\left(C - p - CF + \frac{CF}{k}\right)} \qquad (2)$$

The rms current for the entire cycle corresponding to the periodic current (i_k) is

$$i_r = \sqrt{i_k^2 k} = I\sqrt{\frac{k}{1-p}\left(C - p - CF + \frac{CF}{k}\right)} \qquad (3)$$

For a motor with a service-factor rating, let

S_1 = service factor
i = continuous rating current
S_3 = ratio of rms current to continuous rating current

Then

$$L_r = pL + S_1^2(1-p)L \qquad (4)$$

Also

$$L_r = L_c + \left(\frac{i}{I}\right)^2 L_s$$

from which

$$i = I\sqrt{\frac{C-p}{1-p}}$$

Then

$$S_3 = i_r/i = \sqrt{\frac{k}{C-p}\left(C - p - CF + \frac{CF}{k}\right)} \qquad (5)$$

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A New Type of Adjustable-Speed Drive for A-C Systems

A. G. CONRAD, MEMBER AIEE
S. T. SMITH, Enrolled Student AIEE
P. F. ORDUNG, Enrolled Student AIEE

Synopsis: This paper describes the theory and characteristics of a new type of polyphase adjustable-speed motor and its control circuit. The system provides an a-c drive that has characteristics comparable to those of the Ward Leonard system used on direct currents. The control circuit provides starting as well as speed adjustments from 0 to 100 per cent of rated value. The power factor of the motor is either leading or very close to unity over its operating range, and consequently the efficiency is high. Low costs of this type of motor and its control system, the large speed range, the facility for rapid reversal by regeneration, and its high starting torque make it suitable for some industrial applications.

ATTEMPTS to adapt d-c shunt motors for use on alternating currents have been unsuccessful because of the difficulty in producing a flux that is in time phase with the armature current. In order to obtain a high power factor and a large torque, such a motor would have its armature current under load inphase or approximately inphase with both the armature voltage and the air-gap flux. These conditions are unattainable in the a-c shunt motor. When the field and armature are supplied with the same voltage, the phase of the field current is approximately 90 degrees behind that of the voltage. The flux produced by the field is approximately in quadrature with the armature voltage. The armature current is more nearly inphase with the armature voltage, and consequently it cannot be inphase with the flux. In addition to this the generated voltage produced by rotation of the armature in the field is approximately 90 degrees out of phase with the applied voltage instead of being directly opposed to it as in a d-c motor. Consequently the armature current is limited largely by the impedance of the armature, and speed has little effect on this current. Thus the single-phase shunt motor used on alternating current will take very large currents at all loads, and, since changes in generated voltage have little effect on this armature current, increases in load will cause large reductions in speed. The speed regulation of such a motor is objectionably high.

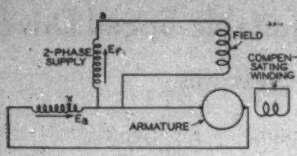
The undesirable features referred to above can be overcome by adapting the motor for use on polyphase systems in a manner such that the voltage applied to the field is approximately at right angles in time phase with respect to the armature voltage. Under such conditions the inductive effect of the field will cause the air-gap flux to be approximately inphase with the armature voltage. The generated voltage in the armature due to rotation will oppose the applied voltage, causing the motor to behave very much like a d-c shunt machine. Thus in Figure 1, if the field and the armature of a motor are supplied from separate phases of a two-phase system, the motor would take a small armature current at no load and an increased current when load is applied. The armature current would be out of phase with the armature voltage, and, because of the large armature impedance, the speed regulation would be similar to that of a shunt motor with a large resistance in its armature circuit.

The Motor and Its Circuits

Objections to the two-phase motor shown in Figure 1 can be overcome by

Paper 43-3, recommended by the AIEE committee on electrical machinery for presentation at the AIEE national technical meeting, New York, N. Y., January 25–29, 1943. Manuscript submitted June 3, 1942; made available for printing October 20, 1942.

A. G. Conrad, S. T. Smith, and P. F. Ordung are with Yale University, New Haven, Conn., where Professor Conrad is associate professor of electrical engineering and Mr. Smith and Mr. Ordung are graduate students in the Yale School of Engineering.



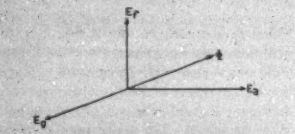
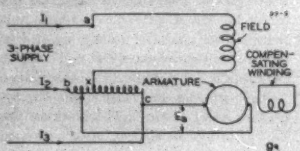


Figure 1. The motor supplied with two-phase voltages and its vector diagram



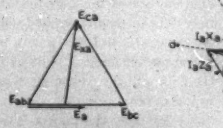


Figure 2. The motor supplied with three-phase voltage and the voltage vectors

proper design of the motor and by supplying the field with a voltage that is in proper phase relationship with respect to the armature voltage. The armature should be designed with the lowest value of impedance practicable. This requires a compensating winding on the stator which can be connected either in series with the armature or short-circuited—the latter connection produces inductive compensation. The voltage applied to the field should be shifted in time phase with respect to its quadrature position shown in Figure 1, so that the time phase of the air-gap flux is slightly behind the armature applied voltage. This shift is essential in order that the power factor of the motor be kept high and can be accomplished in the circuit shown in Figure 1 by connecting the field across the points a and x.

The methods of obtaining this slight shift of voltage on polyphase systems are numerous. The requisite voltages for field and armature referred to above can be obtained from a three-phase supply by use of the circuit shown in Figure 2. The motor has an armature similar to that of an ordinary repulsion motor. The compensating winding is placed on the stator in such a position as to neutralize the flux produced by the armature ampere turns. The main field winding is placed on the stator and is spaced 90 electrical degrees with respect to the compensating winding. Three-phase voltage is supplied at the points a, b, and c, and an adjustable transformer is connected between b and c. The motor armature can be supplied with all or any portion of the voltage between the points b and c. Selection of speed is obtained by adjustment of this armature voltage. The field winding is connected between line a and point x on the adjustable transformer. The field winding acts as a transformer in making essentially a three-phase to two-phase transformation of voltages. This differs from the ordinary Scott connection in that the point x is not exactly midway between b and c.

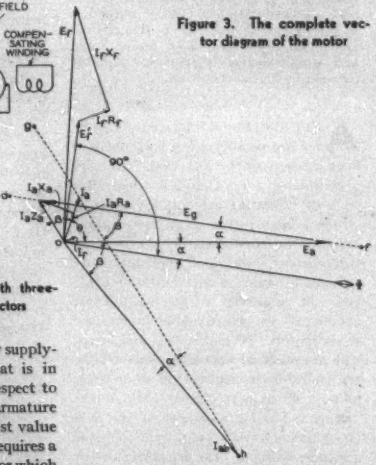


Figure 3. The complete vector diagram of the motor

Theory of the Motor

The theory and operation of the motor connected as in Figure 2 can be explained on the basis of its vector diagram shown in Figure 3. This is the diagram for a two-horsepower motor constructed in accordance with the required features described above. The field voltage is shown as the vector E_f, and for this particular case it is almost perpendicular to the armature voltage vector E_a. The phase angle between these voltages can be changed by moving the tap x on the control transformer. In the analysis presented here it is assumed that the armature and field voltages remain constant and fixed in direction for all values of load and that the impedance of the control transformer is negligible.

When voltage is supplied to the field of this motor, the back electromotive force in the field is produced by a resistance drop, a drop due to the mutual flux that cuts the armature and the field conductors, and a drop due to the leakage flux which cuts the field winding but not the armature. The vectors representing these voltages are shown in Figure 3. The voltage applied to the field is E_f, the leakage-reactance voltage drop is $I_f X_f$, and the voltage produced in the field winding by the mutual flux is E_f'. The mutual field flux that generates the voltage E_f' in the winding is represented by the vector ϕ.

If the armature voltage E_a is applied while the rotor is held stationary, the armature current will be limited by the equivalent resistance and reactance of the armature circuit. The equivalent resistance R_a is determined by the effective resistance of the armature circuit plus the resistance of the compensating winding reflected to the armature; whereas the equivalent reactance X_a is determined by the closeness of coupling of the compensating winding to the armature. Thus the blocked-rotor armature current I_{ab} is equal to the voltage E_a divided by the impedance Z_a of the armature circuit, where

$$Z_a = \sqrt{R_a^2 + X_a^2}$$

The current I_{ab} shown in Figure 3, lags the armature voltage by the angle β where

$$\beta = \cos^{-1}\frac{R_a}{Z_a}$$

β is also the angle between the voltage $I_a Z_a$ and the current I_a, where I_a is the armature current for any value of load

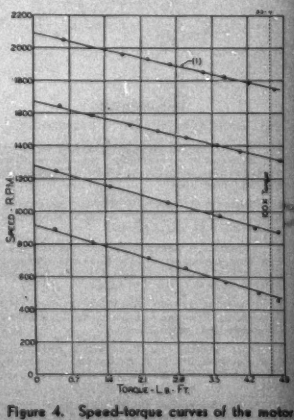


Figure 4. Speed-torque curves of the motor for different values of armature voltage

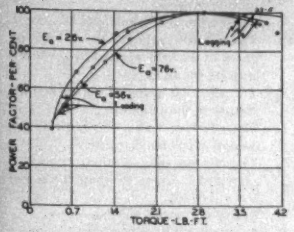


Figure 5. Power-factor curves for different speed settings

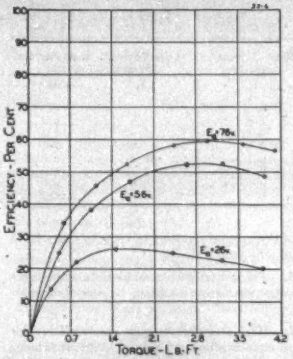


Figure 6. Efficiencies for different speed adjustments

The current I_{ab} acting on the flux ϕ produces torque. If the motor is allowed to rotate, a counterelectromotive force similar to the back electromotive force in a direct-current motor will be generated. This generated voltage E_g will have the same time phase as the flux ϕ, since it is proportional to the product of the flux and speed. Therefore the generated voltage vector E_g is parallel to the flux vector ϕ, and the magnitude of E_g is proportional to the speed of the motor if the flux is constant. The sum of the voltages in the armature circuit must equal the applied voltage, or expressed as an equation

$$I_a Z_a + E_g = E_a$$

In this relationship the voltage E_g has a fixed direction but can change in magnitude as explained above; however the voltage E_a is constant in both direction and magnitude as assumed. Therefore the term $I_a Z_a$ has a variable direction and magnitude such that the above equation is satisfied.

For an increase in speed, the magnitude of the vector E_g in Figure 3 increases along the dotted line fd—this line is parallel to the flux vector ϕ. The terminus of the vector $I_a Z_a$ must always lie along the dotted line fd in order that the vector sum of $I_a Z_a$ and E_g be equal to the vector E_a. Thus the extremity of the vector $I_a Z_a$ has the straight line locus fd. Since the changes in the brush resistances are small over the operating range of the motor, the armature impedance Z_a is essentially constant. The armature current I_a is proportional to $I_a Z_a$; therefore, the terminus of the vector I_a also follows a straight-line locus in the same manner as the vector $I_a Z_a$. The locus of I_a, shown as the dotted line gh in Figure 3, is displaced from the line df by the impedance angle β. The vector $I_a Z_a$ must lead the armature current vector by the impedance angle β.

The power developed is equal to the projection of E_g on I_a multiplied by I_a, and the copper loss in the armature circuit is equal to the projection of $I_a Z_a$ on I_a multiplied by I_a. At no load the developed power is small, therefore the current vector I_a is approximately perpendicular to the vector E_g. For the condition of no load the armature current I_a as shown by the vector diagram is leading the applied voltage E_a. When the machine is loaded, there is a slight reduction in speed and consequently a reduction in the magnitude of the vector E_g. This change in E_g causes a change in the magnitude and direction of the vector $I_a Z_a$—such that its extremity moves along its locus df. This clockwise shift of the vector $I_a Z_a$ is associated with an equivalent shift in the current vector I_a. The locus of the terminus of the vector I_a is gh. Thus an increase in load is associated with a reduction of speed. The torque supplied to the shaft is represented by the projection of the current vector I_a on the flux vector ϕ (Figure 3). Expressed as an equation

$$T = K \phi I_a \cos(\alpha + \theta)$$

where θ is the power-factor angle of the armature circuit. This angle θ is considered plus for leading power factors and minus for lagging power factors. The factor K is a constant and α is the angle between the flux vector ϕ and the voltage vector E_a.

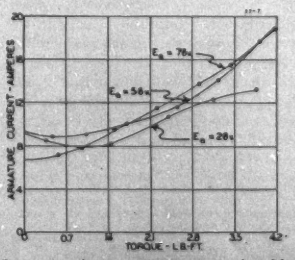


Figure 7. Armature-current curves for different speed adjustments

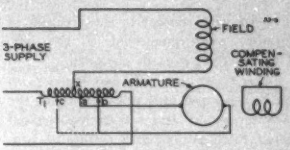


Figure 8. Circuit for reversing drive

Performance

Experiments conducted on a motor supplied as shown in Figure 2 reveal that the characteristics predicted from the vector diagram of Figure 3 check the performance characteristics of the motor. The speed-torque characteristics of this motor with different values of impressed armature voltage are shown in Figure 4. These speed-torque curves are straight lines and are parallel. For the high-speed setting the speed regulation of the motor is approximately nine per cent. These speed-torque curves indicate that the motor has an extremely high starting torque. Selection of speed can be accomplished by adjusting the armature voltage E_a. The power factor of the armature circuit for different speed settings is shown in Figure 5. The corresponding efficiency and armature current curves are shown in Figure 6 and Figure 7 respectively.

Since one of the three-phase lines to the motor carries only field current, while each of the other two lines carries the transformed armature current and a portion of the field current, the three line currents supplying this system must be unbalanced. The extent of unbalance for approximate equal intervals of load from no load to full load for the performance curve 1 of Figure 4 is indicated in Table I.

Additional Control Features

The motor described here can be easily adapted for reversing operation by the use of the circuit shown in Figure 8. In this circuit one side of the armature is connected to the mid-tap of the transformer. The other side of the armature can be connected to either side of the mid-tap for operation. When connected on the right (Figure 8) of the mid-tap, the direction of rotation of the motor will be

reversed with respect to its direction of rotation when connected to the left. Thus reversing is easily obtained.

Other types of transformer connections can be used to supply this motor with the same terminal voltages as those discussed here. Such connections naturally provide the motor with the same operating characteristics. Field control can be added in these circuits, but it usually results in poorer motor characteristics. A slight amount of saturation in the field provides fair speed regulation in the motor. Weakening the field will cause an increase in speed, but it will also cause an increase in the speed regulation.

If the sliding contact is moved rapidly toward the other armature supply tap on the adjustable transformer, there will be a rapid reduction of the armature voltage E_a. This causes a reversal of the power component of the armature current. The machine will act as a generator, and high braking action will result. Thus the same control apparatus used for starting and controlling the speed can be used for braking.

Conclusions

1. The theory of a new type of adjustable-speed drive for use on alternating currents is presented here.

2. The theory is verified through experiments conducted on a two-horsepower motor and its controller. Performance of the system was found to be meritorious.

3. The system provides speed adjustment for either direction of rotation.

4. The speed range is from 0 to 100 per cent of the rated armature speed.

5. By proper adjustment the power factor of the motor is leading or close to unity from no load to full load.

6. The controller consists of an adjustable autotransformer and can be mounted independently of the motor itself.

7. High starting torques are available for accelerating heavy loads or loads with large inertias.

8. No energy is lost in starting resistors in this type of control. The system has smooth accelerating characteristics from standstill to maximum speed.

9. Since the armature currents on starting are supplied at low voltage, the input currents to the system are small, thereby eliminating line-voltage disturbances normally associated with motor starting.

10. Rapid acceleration and deceleration are provided in the control circuit.

11. Efficiency of the system is comparatively high.

12. Simplicity of the control circuit and its manifold uses make the unit relatively inexpensive.

13. The unbalance of line currents makes its application to large motors undesirable. The unbalance produced by small motors of this type is not objectionable.

Table I

Field Current Amperes	Line Currents Supplying the Armature Amperes	
I_1	I_2	I_3
9.5	12.2	6.1
9.5	13.0	6.0
9.5	15.1	7.1
9.5	16.4	8.0
9.6	17.4	8.2
9.6	19.3	9.7
9.6	22.9	13.5

List of Symbols

E_a—The voltage applied to the armature.

E_f—The effective value of the voltage applied to the field winding of the motor.

E_f'—The effective value of the voltage induced in the field winding by the flux ϕ crossing the air gap.

E_g—The effective value of the generated voltage in the armature.

I_a—The effective value of the armature current expressed in amperes.

I_{ab}—The effective value of armature current expressed in amperes when the motor is at standstill.

I_f—Effective value of the field current.

K—A constant for any particular motor involving the total number of turns on the armature, the number of parallel paths, and the number of poles.

R_a—The equivalent resistance expressed in ohms of the armature and compensating winding.

R_f—Resistance of the field winding.

T—The developed torque of the motor expressed in pound-feet.

x—The point on the adjustable transformer at which the field is connected.

X_a—The equivalent reactance of the armature and compensating winding expressed in ohms.

X_f—The effective reactance of the field winding expressed in ohms caused by the leakage flux that does not cross the air gap.

Z_a—The equivalent impedance of the armature and compensating winding expressed in ohms.

α—The phase angle expressed in electrical degrees between the generated voltage and the applied armature voltage.

β—The angle having a cosine that is equal to the ratio of the armature resistance R_a to the armature impedance Z_a.

θ—The phase angle or power-factor angle in electrical degrees between the impressed armature voltage E_a and the armature current I_a.

ϕ—The total flux per pole crossing the air gap expressed in maxwells.

A New Generator Differential Relay

A. J. McCONNELL
ASSOCIATE AIEE

"RELAYS have been available for years capable of providing selective high-speed protection if—and it is a big IF—the intelligence transmitted to the relay closely approximates the truth." This statement, recently made by a protection engineer, is a true statement, the import of which is not always fully recognized.

Regarding current supply, there are many relay applications for which orthodox current transformers are quite adequate. On the other hand, applications such as differential relaying require careful consideration of the current-transformer characteristics. If a high-speed differential relay is desired, transient, as well as steady-state characteristics must be studied. The reason for this is the probability of false differential current flow occasioned by d-c saturation of a current transformer excited by an offset current.[1]

There has been a gradual improvement in the steady-state characteristics of current transformers.[2] Also, the transient problem has been attacked by increasing the size of the core, by inserting air gaps in the magnetic circuit,[3] or by eliminating the iron entirely.[3] By and large, however, the major portion of differential-relay development has been concerned solely with the design of relays capable of overcoming the inherent deficiencies of standard current transformers. There is no better example, in support of this statement, than the protection of generators against internal faults.

As of today, what better protection could be imagined than the very first instantaneous overcurrent relay, connected differentially, if the currents supplied to the relay were true representations of the actual primary currents? Actually, however, there have been at least five generator protective-relay developments, all concerned with the inadequacy of the current supply. Briefly, the chronology has been somewhat as follows:

(*a*). Time-overcurrent relay connected differentially.[4,5] False current-transformer output requires high minimum operating current, or long operating time, or both, in order to prevent improper relay operation.

(*b*). Percentage- or ratio-differential relay (relatively slow speed).[4] Such a relay is provided with a restraining force dependent upon the sum of the currents entering and leaving the zone of protection. During a fault external to the protected zone, it operates only if one current is a certain percentage above the other (slope). Figure 1, curve *A*, shows the operating characteristic of one such relay.

(*c*). High-speed percentage- or ratio-differential relay. Such relays have had only limited success because of the high false differential current possible, as above noted, during transient conditions.

(*d*). Harmonic-current-restrained differential relay.[7] Although transformer and bus relays of this type have been successfully applied, the harmonic-current-restraint principle has never been extended to generator protection because of design limitations attending the requirements of high sensitivity and ability to withstand heavy fault currents.

(*e*). Relay utilizing both (1) variable ratio (variable slope) and (2) the out-of-phase relationship between the differential and restraining currents during heavy through faults[8] (Figure 1, curve *B*) shows a variable-slope characteristic with all currents in-phase.

(*f*). A new differential relay, described herein, the restraining force of which is obtained by means of a principle heretofore unused. It restrains in response to the product of the currents entering and leaving the protected zone, and, consequently the new principle is called "product restraint." In addition, the relay has a slope which is variable and which increases very rapidly above approximately twice normal current (Figure 1, curve *C*).

Limitations of Variable Slope With Summation Restraint

In order to appreciate fully the principle, product restraint, it is necessary first to consider the limitation of variable ratio or slope as applied to a relay using the orthodox summation restraint.

Variable ratio or slope, as the names imply, signifies that the slope of the through-fault operating characteristic continuously changes, as shown by curve *B* of Figure 1. In order to be really effective, however, the slope should increase rapidly above maximum full-load current of the machine, perhaps as indicated by curve *C* of Figure 1. To obtain such a relay characteristic, it is apparent that, as the current increases, the operating force must become deficient relative to the restraining force. However, assuming summation restraint, a relay with this characteristic could fail to operate under certain internal fault conditions. For example, if the internal fault is fed only by the protected generator (that is no external source), the restraining and the differential currents are identical. Figure 2 shows curves for the operating and restraining forces of a relay with a variable slope, summation restraint, and identical restraining and operating currents. For currents above the intersection of the curves, the relay will fail to operate, because the restraining force is in excess of the operating force.

For simplicity, it was considered that the curves of Figure 2 were based upon an internal generator fault without an external source of feed. Actually, the danger of failure to operate may be greater when there is an external source. With equal currents fed from the protected generator and an external source, the restraining force of a summation restraint relay is theoretically zero. However, the current from the external source may be much greater than the current supplied from the protected generator (for example: there may be several generators on the same bus). Consequently, the restraining force may be much greater when there is an external source than when there is not, and there may be a greater possibility of nonoperation. For example, assume a generator bus with four identical generators connected to it (and no other source of power). The total fault current during a bus fault is four times the current supplied by each generator. If the fault is on the leads of a generator (within its differentially protected zone), the differential current is four times and the net restraining current is twice the respective currents for a fault on the generator leads

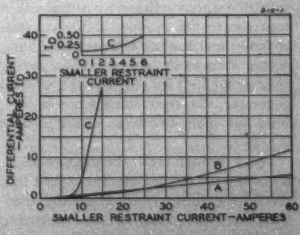


Figure 1. Through-fault operating characteristics of three kinds of differential relays

Restraining and differential currents in phase

Paper 43-15, recommended by the AIEE committee on protective devices for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted October 30, 1942; made available for printing November 27, 1942.

A. J. McCONNELL is with the central station engineering department, General Electric Company, Schenectady, N. Y.

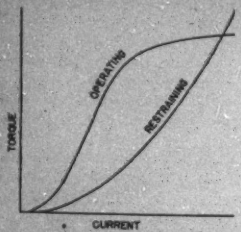


Figure 2. Torque curves of saturated operating element and unsaturated restraining element (summation restraint illustrating possible failure to operate on internal fault)

Figure 3. Directions of currents in current transformers during external fault

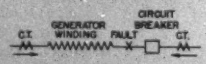


Figure 4. Directions of currents in current transformers during internal fault

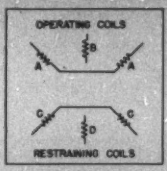


Figure 5. Coil locations in product-restraint differential-relay element

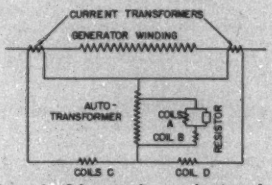


Figure 6. Schematic diagram showing relay and auxiliaries for one phase

with no external source. Relative to the current at the intersection of the curves of Figure 2, doubling the restraining current increases the restraining force to four times, whereas increasing the operating (differential) current to four times increases the operating force by much less than four times. Hence, the increase in restraining force relative to operating force increases the possibility of failure to operate when there is an external source.

Product Restraint

In order to retain the desired through-fault characteristic, curve *C* of Figure 1, and yet provide positive operating margin during an internal fault, it is necessary that the restraining force be greatly reduced, or, preferably, entirely eliminated during an internal fault. The latter result can be accomplished by restraining in response to the product of the currents entering and leaving the protected zone, rather than to their sum. Thus, during an internal fault fed only by the protected generator, the restraining force is zero, since one of the two terms of the product is zero.

For a through fault, the relative polarity of the restraining winding is such that the force is in the contact-opening direction. For an internal fault, assuming that the generator is connected to another source of power, the relative direction of the fault currents is reversed so that the so-called restraining windings will actually produce a contact-closing force. Thus, the windings which provide the restraining force during a through fault, produce, in so far as fault current is concerned, either an operating force or no force during an internal fault.

A somewhat different conception of the operation of this relay results if the relay is considered to be primarily a directional relay. Figure 3 shows that, for an external fault, the current flow is in the same direction in the current transformers on opposite sides of the generator winding. Figure 4 shows that the short-circuit currents in the two current transformers are in opposite directions during an internal fault.

If Figure 4 were true under all conditions, a current polarized directional relay, one winding connected to each current transformer, would provide adequate protection against internal faults. However, there are two conditions during which Figure 4 is in error. First, there may be no external source, in which case the directional relay would fail to operate. Second, load current appears to the directional relay to be an external fault of relatively low current magnitude as in Figure 3. If the internal fault current is low, the load current may outweigh the fault current, thereby preventing the current reversal required for relay operation.

In order to provide sensitive operation with load current flowing and to permit operation when there is no external source of power, a differentially connected overcurrent relay can be added to the directional relay, both relays acting upon a single shaft. Although it is necessary that the overcurrent element be sensitive in order that low values of short-circuit current may overcome the effect of load current, it is not necessary that the overcurrent element torque ever be greatly in excess of the restraining torque of the directional element under maximum load current conditions. This fact permits sharp saturation of the differential current circuit, thereby causing the relay to be stable during external faults, even with the large false differential currents which may be present at the higher current levels.

Figure 7. Three-phase product-restraint differential relay

Description of Relay

The relay unit using the product-restraint principle is of the eight-pole, induction cylinder construction previously described before the Institute.[9] The available poles permit both the differential-operating and the product-restraining functions to be accomplished in a single unit. Although a single relay unit is described, it should be understood that three such units are required for a three-phase circuit.

Figure 5 shows the locations of the various coils on the eight-pole structure. The upper three coils, denoted by *A* and

B, are the differential-operating coils, while the lower three coils, *C* and *D* provide the product restraint.

Figure 6 shows schematically the connections of the various coils to the current transformers spanning the protected zone.

Figure 6 indicates that the differential current is not supplied directly to the upper coils of Figure 5, but, rather, indirectly through an autotransformer. The autotransformer, which saturates at a relatively low current, provides the greatly increasing slope characteristic as the through-fault current increases. It also permits the use of relatively large wire in the differential circuit, thereby facilitating testing at the higher currents without the overheating usually encountered in testing generator differential relays.

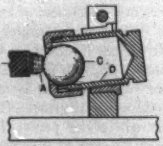


Figure 8. Cross-sectional view of relay backstop

It will be noticed that a resistor is used in the circuit of coils *A*. This resistor is for the purpose of shifting the phase of the current in the outer poles to obtain a torque-producing component. The necessary phase shift of the product-restraining coils is obtained easily in the relay unit itself by means of a flux-shifting copper tube.

Figure 7 shows a three-phase relay, all auxiliaries of which are mounted behind the relay units. Those familiar with this construction will recognize the usual bounce-suppressing contact on the left-hand side of the upper structure of each relay unit. Because of constructional similarity, there appears to be a contact on the right-hand side also. However, the tube or "barrel" on the right-hand side is a new type of backstop construction which prevents closing the tripping contacts upon the release of a through-fault restraining force. This backstop has another desirable quality in that it acts as a shock-suppressing device. The relay can be set as low as 0.1 ampere at no load, as indicated by the insert of Figure 1. However, for practical purposes 0.2 ampere is sufficiently low, and a relay calibrated at this value will be safe against false operation, even under unusual shock conditions.

Figure 8 shows a cross-sectional view of the backstop. Felt pad *A*, attached to the moving contact arm *B*, normally rests against stainless-steel ball *C*, which in turn is free to roll in race *D*. The race is inclined sufficiently to cause the ball to retain the contact arm in the position shown under normal conditions with full load current flowing. Upon the occurrence of an external fault, the restraining torque causes the moving contact arm to force the ball to the right, opening the contact gap and thereby effectively preventing the stored energy from causing contact closure upon the release of that energy when the external fault is cleared. Regarding the shock-resistant quality of the backstop, consider first the action of a solid backstop following a blow from the right. The energy of the impact would be transmitted, with practically no attenuation, to the moving contact arm, causing it to move to the left, or contact-closing direction. With the backstop of Figure 8, a blow from the right causes race *D* to move sharply to the left. However, since the ball is free to move relative to the race, the inertia of the ball causes it, together with the moving contact, to remain substantially motionless in space.

Relay Characteristics

The typical through-fault operating characteristic of this relay is that previously referred to as the "desired characteristic," curve *C* of Figure 1. The insert of Figure 1 shows the same curve at low current levels and can be used for internal faults, the abscissas then indicating the load currents. Any further attempt to depict the internal fault characteristic would be quite meaningless, since, as previously explained, a flow of short-circuit current from an external source causes an operating force to be produced by the so-called restraining windings and thereby, in effect, reduces the minimum operating current of the relay.

The relay is of the high-speed type as indicated by the time-current curve, Figure 9.

The burden of the restraining coils is very low, approximately 0.08 ohm total. The burden of the operating-coil circuit is a variable, reaching a maximum of 65

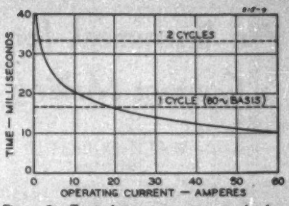


Figure 9. Typical time-current curve of relay with restraint corresponding to full load

ohms. This seems high but is actually comparable with, if not less than, the burdens of other generator differential-relay operating circuits.

Conclusion

A generator differential relay has been described which approaches the ideal of fast sensitive protection equivalent to that attainable with perfect current transformers. Because the product-restraint principle permits a variable slope without its usually attendant "blind-spot" danger, the relay can be applied with a minimum of effort.

Thus far, the generator differential relay is the only relay to which the product-restraint principle has been applied. This development was completed before December 7, 1941, but further extension of product restraint such as to transformer, pilot wire, or bus differential relays, must await normal times.

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An Instrument for the Determination of Contact Making and Breaking Time

WALTHER RICHTER
FELLOW AIEE

WILLIAM H. ELLIOT
ASSOCIATE AIEE

Synopsis: This paper describes an electronic instrument for the measurement of the arcing time of a contact closing or opening a circuit. This measurement is accomplished by permitting a current of constant value to flow into a capacitor during the time that an arc exists across the contacts under observation; the charge accumulated on the capacitor is therefore a measure of the arcing time. The instrument also contains electronic means of measuring the charge on the capacitor, by determining the voltage existing across it at the end of the measurement. The circuit serving this purpose is a Wheatstone bridge with a tube in one arm, to whose grid the capacitor is connected, and a microammeter in the diagonal which indicates directly the amount of unbalance produced by the capacitor voltage.

The application of the instrument to the investigation of a three-pole contactor is described.

FOR the investigation of contact-making devices such as contactors, relays, and snap switches under various load conditions, a device for the quick determination of the operating time of a contact seemed desirable. As many investigators in the field have found that the making of a circuit often represents a harder service for the contact-making device, because of contact bounce, than the breaking of the circuit, the instrument described in the following paragraphs was originally designed to permit the quick measurement of the bouncing time of a contact, without the need of employing an oscillograph.

The underlying principle of the instrument is very simple; a current of constant and predetermined value is made to flow into a capacitor during the time that the contact is being made or broken, that is, during the time that an arc exists across the contacts. The charge accumulated on the capacitor and with it the voltage appearing across it are therefore proportional to the time of arcing, since the charge is the time integral of the current flowing into the capacitor.

Paper 43-1, recommended by the AIEE joint committee on electronics and the committee on instruments and measurements for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted August 14, 1942; made available for printing October 15, 1942.

WALTHER RICHTER is consulting engineer, Milwaukee, Wis., and WILLIAM H. ELLIOT is development engineer, experimental department, Cutler-Hammer, Inc., Milwaukee, Wis.

Obviously, mechanical relays cannot be used to connect and disconnect the measuring capacitor to and from a suitable charging circuit during the arcing time of the contact-making device under observation, since the error introduced by these relays would be of the same order of magnitude as the time to be measured. A vacuum tube, on the other hand, is a practically inertialess relay and thus offers a convenient solution to this problem. Furthermore, if a capacitor and a tetrode or pentode, properly biased, are placed in series across a fixed d-c voltage, the current which will flow in this series combination, that is, the charging current of the capacitor, will remain practically constant, as a result of the flat plate characteristics of these types of tubes, until the voltage across the tube has been reduced to a relatively low value. A nearly linear relation between time and accumulated charge is thus obtained.

Figure 1 shows that part of the circuit which accomplishes the charging of the capacitor. It is seen that the capacitor is placed in series with a pentode across a suitable d-c voltage. The capacitor is by-passed by the meter M_1 and the normally closed switch S_2, which is opened just before a measurement is taken and is kept open only until the measurement is completed. The grid bias of the pentode consists of voltage drops caused by currents flowing in the resistors R_1 and R_3, as will be explained in more detail later. During the adjustment of the charging current to a suitable value, as well as during the actual arcing time, no current flows through R_3, and the bias voltage consists only of the voltage drop e_o across R_1. This voltage is of constant value and such that it permits plate current to flow, the amount being adjustable to any desired value by varying the screen grid voltage obtained from the potential divider P_1. If switch S_2 were opened at this moment the plate current, which up to this instant was indicated by the meter M_1, would flow through the capacitor, charging it linearly with time. Switch S_2 is not opened, however, until additional bias, furnished by a current flowing through resistor R_3, has biased this tube beyond cutoff.

It now becomes evident that means must be provided to maintain a current flow through R_3 sufficient to bias the charging tube to cutoff, except during the arcing time of the contacts under observation, at which time the current flow through R_3 should be reduced to zero, so that the previously adjusted charging current will flow into the capacitor, as already explained. Furthermore, the instrument should indicate directly the charge accumulated on the capacitor during this period. The circuits accomplishing this are shown in Figure 2.

A conventional rectifier system furnishes the necessary d-c voltage; two voltage-regulator tubes in series keep the supply voltage constant. Previous to an actual measurement switch S_1 is opened, which prevents any possible current flow through R_3 and thus permits the adjustment of the plate current, as outlined above. S_2 is kept closed, of course, during this operation. Consider now the two control tubes V_1 and V_2. Resistance R_4 is common to both plate circuits. If either one of these tubes is made sufficiently conducting, the current flow in this resistance will make point H negative with respect to point F, or, in other words, the voltage across the control tubes will be less than the voltage across R_5. With switch S_1 closed, current will therefore

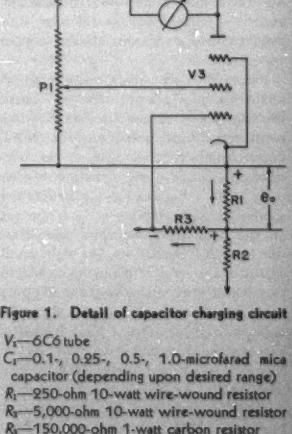

Figure 1. Detail of capacitor charging circuit

V_1—6C6 tube
C_1—0.1-, 0.25-, 0.5-, 1.0-microfarad mica capacitor (depending upon desired range)
R_1—250-ohm 10-watt wire-wound resistor
R_3—5,000-ohm 10-watt wire-wound resistor
R_5—150,000-ohm 1-watt carbon resistor
P_1—5,000-ohm wire-wound potential divider
P_2—1,000-ohm wire-wound potential divider
M_1—0–1-milliampere d-c meter

flow from point F through R_3 and the diode to point H. This provides the additional bias voltage needed to cut off the current in the charging tube. If the current flow through R_4 is reduced to such a value that point H becomes positive with respect to point F, the current through R_3 ceases, since the diode prevents a reversal of current, and the charging tube passes the previously adjusted current.

The contact to be investigated in series with a suitable load is connected across a d-c source with a polarity as shown in Figure 2. A resistor R_{10}, acting similarly to a shunt, is included in the circuit. Its resistance should be such as to produce a voltage drop of at least 0.25 volt with the lowest value of load current. This voltage drop furnishes a negative bias to one of the control tubes, whereas the second control tube receives a negative grid voltage when a voltage exists across the contacts. It is evident, therefore, that before the contact closes, V_2 will be biased negatively, whereas V_1 will have zero grid voltage (since no current flows in the shunt); V_1 will consequently be conducting, its plate current passing through R_4. After the contact is established firmly, however, V_1 will become nonconducting as a result of the bias produced in the shunt, whereas V_2 will now become conducting. The inclusion of a dry cell in the grid circuit of this tube serves to overcome any possible effects caused by contact resistance. It is seen that during the period of arcing both control tubes will be biased negatively, V_1 by the voltage drop across the shunt and V_2 by the arc voltage existing across the contacts. Current flow through R_4 is therefore reduced or ceases entirely during the arcing period, which in turn permits current flow in the charging tube, as explained above. Since S_2 is opened just before a measurement is taken, a charge will accumulate on the capacitor.

The remaining circuit element serves to measure the voltage across the capacitor. Any device for this purpose—unless a ballistic method were to be considered—must draw no appreciable current for the measurement. An electrostatic voltmeter would be the ideal instrument, of course, but for the relatively low voltage to be measured this type of instrument is very delicate. Special tubes, called electrometer tubes, such as General Electric *FP-54* are available, the grid current of which is about 10^{-15} amperes, with a corresponding input resistance of about 10^{14} ohms. Since a charged capacitor will lose its voltage as a result of its own leakage resistance, however, it is obvious that not much is gained by employing an instrument with an input resistance two or three powers of ten higher than the leakage resistance of the capacitor and its associated circuits.

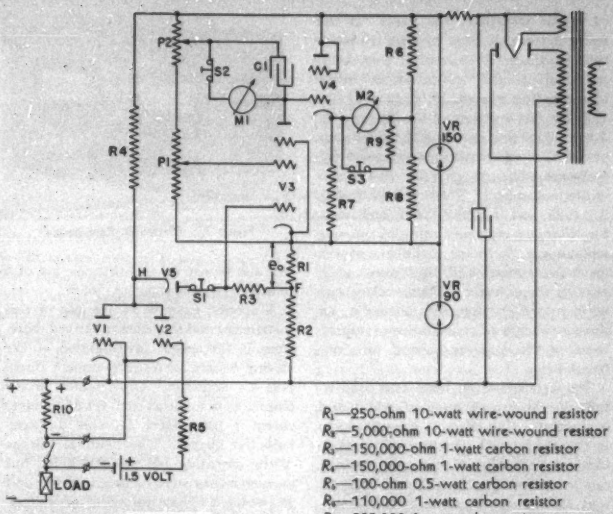

Figure 2. Circuit diagram of instrument

V_1—6F5 tube
V_2—6F5 tube
V_3—6C6 tube
V_4—38 tube
V_5—6H6 tube
C_1—0.1-, 0.25-, 0.5-, 1.0-microfarad mica capacitor (depending upon desired range)
R_1—250-ohm 10-watt wire-wound resistor
R_2—5,000-ohm 10-watt wire-wound resistor
R_3—150,000-ohm 1-watt carbon resistor
R_4—150,000-ohm 1-watt carbon resistor
R_5—100-ohm 0.5-watt carbon resistor
R_6—110,000 1-watt carbon resistor
R_7—225,000 1-watt carbon resistor
R_8—One-megohm 1-watt carbon resistor
R_9—100-ohm 0.5-watt carbon resistor
R_{10}—Shunt (see text)
P_1—5,000-ohm wire-wound potential divider
P_2—1,000-ohm wire-wound potential divider
M_1—0–1-milliampere d-c meter
M_2—0–200-microampere d-c meter

Of the common radio tubes, the type 38 has a grid current of about 10^{-9} amperes when operated with a filament voltage of four volts and with about 30 volts on the screen and plate. This tube is used in the instrument forming one arm of a Wheatstone bridge. The rate of change of capacitor voltage, caused by the combined action of leakage and grid current, is so low in the instrument that the drift of the meter does not exceed one scale division in three or four seconds, so that ample time for taking a reading is available.

Before a measurement is made, the bridge is balanced (that is, meter M_2 is brought to zero) by adjustment of potential divider P_2, which furnishes grid voltage for V_4. Switch S_2 is closed during this adjustment, of course. The meter M_2 can once and for all be calibrated in terms of voltage across the capacitor by simply applying known voltages across it, keeping S_2 open during this calibration. With the capacity of the capacitor known, the charging current adjusted to a known value, and the meter M_2 calibrated in terms of capacitor voltage, all factors for the calculation of the duration of current flow are therefore known. Since the measuring circuit is highly degenerative, because of cathode resistor R_7, the indications of the meter M_2 are practically linear with respect to the capacitor voltage. As a matter of interest, it may be stated that a capacitor voltage of approximately 20 volts produces full-scale deflection on the 200-microampere meter M_2.

Since the action of the instrument depends on the negative bias applied to the two control tubes, the contact under observation can be tested only with direct current. At first sight this might be considered as a serious limitation of the instrument. The addition of relatively simple rectifying circuits, however, would make the use of the instrument on a-c circuits possible. This was not deemed necessary, or even desirable, for the following reason: the performance of a contact in an a-c circuit will naturally depend on the exact instant of the a-c cycle when the contact opens or closes. Thus, a number of readings taken on the same contact will vary widely, unless care is taken to synchronize the contacts to a

particular instant of the cycle. If the test is made with direct current, the latter can be adjusted to any value, thus simulating any desired "instantaneous" value of alternating current.

Figure 3 is a picture of the instrument. A tap switch not shown on the diagram is provided to insert various values of capacitance, thus changing the time range of the instrument. These values are 1.0, 0.5, 0.25, and 0.1 microfarad, and, with the charging current adjusted to one milliampere, full-scale deflection of the meter M_3 represents 20, 10, 5, and 2 milliseconds respectively. These values can be increased or decreased, naturally, by further changes of capacitance or adjustment of the charging current to a different value.

The instrument has been used successfully in the investigation of relays and contactors. The effect of changes made in the mechanical structure of the contactor and the effect of changes in the load can be studied quickly without having to wait for the development and measurement of films taken with an oscillograph. The instrument can also be used for purposes other than determining the arcing time of a contact. Thus, the operating time of relays or solenoids can be determined by inclusion of contacts at the beginning and the end of the travel, furnishing suitable voltages to the terminals of the instrument in place of those produced by the shunt or the arc. The measurement of the L/R ratio of an inductive load

Figure 3. Electronic time gauge

can also be carried out with the aid of a relatively simple external circuit.

A specific example of the use of this instrument and the benefits derived therefrom is the recent investigation of the closing bounce of a 1,200-ampere three-pole a-c contactor. Observations of the bounce were made as each set of contacts closed a 100-ampere 115-volt d-c non-inductive circuit. The nominal voltage of the operating coil was 208 volts, but measurements were included at 195 and 220 volts, so that the effect of voltage variations might be ascertained.

Duration of bounce of the set of contacts behaving most poorly under the original adjustment of the contactor was 4.8, 5.6, and 6.4 milliseconds with coil voltages of 195, 208, and 220 volts respectively.

By increasing the initial contact pressures from the original value to a somewhat higher one, the respective bouncing times were reduced to 2.8, 3.4, and 4.5 milliseconds.

After increasing the wear allowance of the two outside sets of contacts slightly, setting the middle movable contact ahead of the others by one-eighth inch, and closing an orifice in the dashpot which allowed quick motion at the start of the armature stroke, the durations of bounce were 1.2, 1.4, and 1.7 milliseconds, respectively.

And, finally, after decreasing the clearance between the piston and cylinder of the dashpot assembly, the bounce durations were found to be 0.3, 0.3, and 0.5 millisecond.

Within a few hours time, therefore, it was possible to observe the effect of several variables upon the action of the contactor and to reduce the duration of closing bounce to about seven per cent of its original value. To accomplish this by means of an oscillograph would obviously have required a considerably greater expenditure of time and effort.

In another case, it became necessary to reduce the time required for a small relay to interrupt a circuit. Observations were made thereupon of the duration of the opening arc both with and without blowout assemblies. The arcing time without a blowout, for example, was found to be 14 milliseconds, with a coil-type blowout 7.5 milliseconds, with a tool steel magnet blowout 2.6 milliseconds, and with an Alnico magnet 2.2 milliseconds. The effectiveness of numerous magnet designs was thus readily observed, and an educated selection made of the most suitable one for the purpose.

Correlation of System Overvoltages and System-Grounding Impedance

AIEE COMMITTEE ON PROTECTIVE DEVICES
Working Group on Correlation of System-Grounding Impedance

Synopsis: This report summarizes available data and engineering opinions on the subject of power-system overvoltages, particularly as to their correlation with system grounding impedance. It is hoped that the report will be useful in connection with overvoltage problems for all types of power-system apparatus.

THE characteristics of power-system connections with respect to ground have long been recognized as having an important bearing on many phases of system operation, including overvoltages between line conductors and ground.[1,2] As early systems (which were of the ungrounded type) became extended, operating experience became unsatisfactory because of the occurrence of multiple faults at the same or different locations resulting from an initial ground fault. Since troubles of this nature were frequently thought to be associated with arcing faults, such faults became broadly classified as "arcing grounds." Difficulties thought to be attributable to this type of fault were one of the main factors leading to the general practice of grounding power systems. However, the correlation of system overvoltages with the various forms of grounding and the values of grounding impedances was so complicated that many years elapsed before much progress was achieved, and even now many conditions are incompletely classified.

Causes of System Overvoltage

In a study of system overvoltage phenomena and their correlation with system-grounding impedance, it is convenient to list the causes. Causes of system overvoltage (other than lightning) may be classified as follows:

1. Conditions resulting in sustained overvoltage:
   (*a*). Increase of operating voltage level.
   (*b*). Generator overspeed.
   (*c*). Self excitation.
2. Circuit unbalances:
   (*a*). Open phase or phases.
   (*b*). Unequal pole opening of breakers.
   (*c*). Fuse blowing.
3. Faults:
   (*a*). Solid.
   (*b*). Resistive.
   (*c*). Arcing with forcing of current zero.
   (*d*). Arcing with restriking.
   (*e*). Distortion from saliency effects.
4. Switching operations:
   (*a*). Simple.
   (*b*). Arcing with forcing of current zero.
   (*c*). Arcing with restriking.
   (*d*). Neutral inversion.
5. Extraneous influence from other sources:
   (*a*). Conduction, metallic cross or ground potential, from other power circuits.
   (*b*). Induction, magnetic or electric, from other power circuits.
   (*c*). Electrostatic charging of ungrounded systems by wind-borne particles, such as sand or dust.

Frequently overvoltages result from combinations of two or more of the foregoing factors. In order to define the various causes of system overvoltages, a brief discussion of each type of phenomenon is given.

Conditions Resulting in Sustained Overvoltage

On ordinary power systems overvoltages at fundamental frequency may be produced by:

(*a*). Increase of operating voltage level.
(*b*). Generator overspeed from loss of load.
(*c*). Self excitation of machines.

Five per cent tolerance for emergency operation is the maximum overvoltage above rated circuit voltage recognized by the joint committee on preferred voltage ratings of the National Electrical Manufacturers' Association and the National Electric Light Association.[3] Application procedures for standard rated apparatus are based on this maximum circuit voltage. Sustained overvoltages generally are, under normal conditions, of little importance in regard to voltage stress on apparatus and functioning of protective equipment, but they may become important during or following an abnormal condition, such as produced by a lightning discharge or fault to ground.

It is believed that generator overspeeding and loss of load as single factors without faults or unbalances will seldom give rise to dangerous overvoltages. However, overspeeding may be a contributing factor, especially if it occurs during ground faults. The voltage amplitude is a function of governor characteristics and of means for controlling the excitation. With water-wheel generators without regulation of speed or excitation, the maximum voltage may be as high as 160 to 180 per cent of normal under full-load rejection; whereas with machines under control of modern governors and generator voltage regulators, the voltage will probably be limited to 120 to 140 per cent of normal.

Self-excitation is an infrequent source of overvoltage on systems. It can occur, however, under abnormal circuit conditions which leave relatively small synchronous or induction machines connected to circuits with relatively large capacitance, supplied from lines or capacitors. The possibility of setting up the conditions for self-excitation should be considered in the various stages in the disconnection of faulted circuits.

Sustained overvoltages under unbalanced load conditions may also be produced by saliency effects in machines.[4,5] Solid faults, other than balanced three-phase, sometimes cause the generation of dangerously high harmonic overvoltages in addition to increased fundamental-frequency voltages. These overvoltages are obtained when the system electrical constants and loads are of such proportions as to provide partial resonance to one of the lower harmonics. Magnitudes of overvoltage of this type depend not only on the type of unbalanced fault and the method of grounding but on other system constants as well. Such phenomena are most frequently encountered on systems with water-wheel generators without adequate damper windings, under conditions in which the machines are connected to unloaded or lightly loaded transmission lines with appreciable capacitance and subjected to unbalanced faults.

Circuit Unbalances

On three-phase power systems the opening of one or more phase conductors will, under some circuit conditions, produce large overvoltages between line conductors and ground. These voltages are normally observed on the part of the

Paper 43-5, recommended by the AIEE committee on protective devices for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted October 26, 1942; made available for printing November 2, 1942.

Personnel of working group: W. W. Lewis, *chairman*; J. R. Eaton, R. D. Evans, P. A. Jeanne, J. W. Milnor, H. A. Peterson.

system which is partially separated from the main power source, under conditions with circuit constants such as to provide approximate resonance at fundamental frequency for some path between line conductors and ground. In general, these voltages are encountered on isolated-neutral systems or on systems having relatively high impedance between phase conductors or between phase conductors and ground. These circuit unbalances may arise from open-phase operations, such as occur as a result of conductor breaking, fuse blowing, or the opening of one or more breaker poles. Extreme conditions are produced with two synchronous systems which are out of step but are connected on one phase, the highest voltages being produced with both of the systems ungrounded and one of them subjected to a line-to-ground fault on either of the other two phases.

Faults

Faults cause the most frequently encountered and usually the most important power-system overvoltages. When a balanced three-phase system is subjected to a single or double line-to-ground fault, overvoltages may be produced on the unfaulted phase or phases. The amount of overvoltage may readily be calculated if the system constants, including nonvariable fault resistances, are known. If the fault takes place through an arc, the overvoltages may be increased by two phenomena:

1. The forcing of current zero.
2. Restriking.

Both of these phenomena are discussed at length subsequently.

Switching Operations

Transients resulting in overvoltages of important magnitudes are produced by simple circuit changes involving a single transition from "make" to "break" or vice versa, as may occur on the energizing or de-energizing of a line section. Circuit changes may produce unbalances and thus result in overvoltages resulting from both unbalances and circuit changes. When circuit changes take place through an arcing path, there is also the possibility of increasing system overvoltages through the action of "forcing current zero" or of restriking as mentioned previously in connection with arcing faults. Since switching operations can take place in many ways in opening or closing the several poles of the circuit breaker, and since many transients may be produced for each of these steps, many combinations are possible. Switching operations are normally encountered in combination with other factors including faults and circuit unbalances, so that such transient overvoltages are usually the result of a combination of several factors.

Extraneous Influence

Occasionally a circuit is subjected to voltages which are impressed by conduction from metallic cross or ground-potential effects or by electric or magnetic induction from an adjacent power circuit, usually of higher voltage and capacity. Electrostatic charging of conductors during sand, dust, and sometimes snow storms, occurs in some regions. These effects are readily studied in a particular case if this cause of overvoltage is recognized.

Correlation of Overvoltages With System-Grounding Impedance

The various types of system overvoltages when appearing separately can be correlated with system-grounding impedance, except those that produce overvoltage under balanced conditions, such as emergency operating voltage, sudden loss of generator load, self-excitation of machines, and saliency effects (on line-to-line faults). However, in specific cases each of these types can be so correlated when the overvoltage occurs in combination with a fault to ground or other unbalances with respect to ground.

For correlation with system-grounding impedance, it is convenient to use a different classification from that just used for listing the causes of system overvoltage, basing the classification upon the type of transient phenomenon involved:

1. Simple circuit changes:
   (*a*). Ground faults.
   (*b*). Switching operations.
2. Complex circuit changes through arcing paths:
   (*a*). Forcing current zero.
   (*b*). Restriking arcs.

By a "simple circuit change" is meant a single circuit change that takes place with abrupt transition from "circuit open" to "circuit closed" condition or from "circuit closed" to "circuit open" condition, the opening taking place at a "normal current zero." By a "complex circuit change" is meant one that takes place through an arcing path which introduces additional circuit voltage transients either by

1. Forcing current zero.
2. Re-establishment of a conducting path as with intermittent arcs.

Complex circuit changes in general involve the superposition of a second transient before the effect of the first transient has disappeared.

Simple Circuit Changes

Calculation of Fundamental-Frequency Overvoltage

The simplest and most important, although not necessarily the most severe, types of system overvoltage produced on a power system occur as the result of the application of a single or double line-to-ground fault on a normal balanced three-phase power system. Upon such an occurrence, the sound phases may rise to fundamental-frequency overvoltage with respect to ground as determined by the sequence impedance constants of the system. In addition, there is a transient term which, in simple systems without loss, is equal to the difference between the fundamental voltages before and after the application of the fault. The fundamental-frequency components of overvoltage are of controlling importance in lightning-arrester applications, and the ratios of the fundamental-frequency voltages under fault condition to the normal voltages permit estimating the transient overvoltage magnitudes.

The fundamental-frequency overvoltages that appear on a balanced three-phase system upon the application of a single or double line-to-ground fault are readily calculated for the point of fault by well-known methods based on symmetrical components using the normal voltage before the fault and the sequence impedance constants of the system as viewed from the fault location, including X_0, X_1 and X_2, and the fault resistance or resistances.[4,6,9,11] Voltages at locations other than the point of fault will not as a rule appreciably exceed those at the point of fault, except possibly in case of a very long line, the far end of which has an isolated neutral.

It has been found possible to compare the grounding characteristics of systems by expressing overvoltages to ground in terms of normal voltage (usually on a line-to-neutral voltage base) and by expressing the zero-sequence resistance and reactance as ratios to the positive-sequence reactance.[3] When this procedure is adopted, it is possible to group systems which give the same ratio of overvoltage, although the characteristics of the systems may be radically different. In addition, it is sometimes desirable to give the ratio of the zero- to positive-sequence capacitive reactances. The effect of fault resistance is to increase the magni-

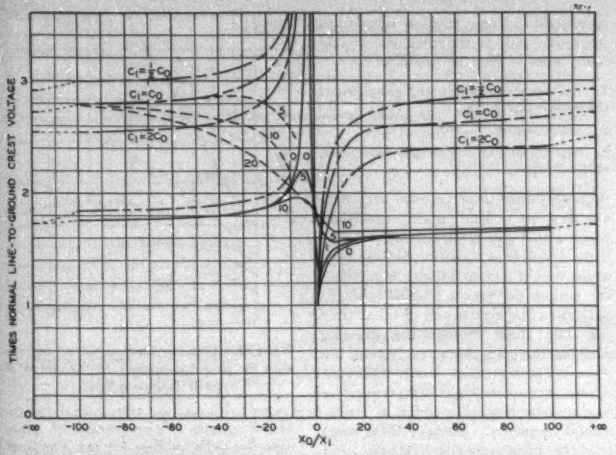

Figure 1. Transient and sustained fundamental-frequency voltages on unfaulted phases during single line-to-ground faults on a three-phase system

$Z_1 = Z_2 = R_1 + jX_1 = 0 + jX_1$
Z_1 = positive-sequence impedance
Z_2 = negative-sequence impedance
R_1 = positive-sequence resistance
X_1 = positive-sequence reactance (subtransient)
X_0 = zero-sequence reactance
C_1 = positive-sequence capacitance
C_0 = zero-sequence capacitance
R_f = fault resistance
All viewed from the fault location

Solid line curves—maximum sustained fundamental-frequency voltage to ground on unfaulted phases with solid single line-to-ground fault. No fault resistance. Numbers on curves are R_0/X_1 ratios

Dash-dot-dot-dash curve—maximum sustained fundamental-frequency voltage to ground with the value of fault resistance which gives the maximum voltage to ground for any value of R_0/X_1. Curve plotted only on negative side, as fault resistance is not as important on the positive side, and additional curves would lead to confusion

Dash-dot-dash curves—maximum transient voltage to ground on unfaulted phases following sudden application of a single line-to-ground fault. $R_0/X_1 = 0$

Dashed curves—maximum transient voltage to ground on unfaulted phases following sudden application of a single line-to-ground fault. $C_1 = C_0$. Numbers on curves are ratios of R_0/X_1. The dash-dot-dash curve for $C_1 = C_0$ is one of this family of curves for $R_0/X_1 = 0$

tude of overvoltage under some conditions and decrease it in others.

Correlation With Different Forms of System Grounding

The preceding discussion has shown the complexity of the problem of correlating overvoltages with system-grounding impedances. To avoid some of these difficulties it has been found expedient to consider five classes of system grounding as follows:

(*a*). Isolated neutral system.
(*b*). Ground-fault neutralizer system.
(*c*). Reactance grounded system.
(*d*). Resistance grounded system.
(*e*). Solidly grounded system.

(*a*). *Isolated-Neutral System.* For isolated-neutral systems of small capacitance to ground and small extent the maximum line-to-ground voltage for a single line-to-ground fault will be equal to the line-to-line voltage before the fault. As the capacitance to ground increases with increasing extent of the system, the maximum voltage to ground will rise above the normal line-to-line voltage and will reach very high values for systems with the ratio of X_0/X_1 in the vicinity of -2. This condition corresponds to approximate resonance in a circuit consisting of the positive- and negative-sequence reactances and the zero-sequence capacitive reactance, all in series. For a double line-to-ground fault the voltages on the sound phase will in general be less than for a single line-to-ground fault except for the range of X_0/X_1 between -2 and 0. In this range there is the possibility of resonance in a circuit consisting of the positive-sequence reactance in series with the negative-sequence and zero-sequence capacitive reactances in parallel. In considering the magnitude of the system overvoltages, it is, of course, essential to consider all circuit conditions and fault locations.[33] Usually the highest overvoltages are encountered on some abnormal condition which leaves a small amount of generating capacity connected to a system of large extent. Practical curves[8,11] for the estimation of the magnitude of overvoltages on isolated-neutral systems subjected to ground faults are available for zero and unit ratios of line resistance to X_1.

(*b*). *Ground-Fault Neutralizer System.* The voltage from a sound phase to ground on a ground-fault neutralizer system will rise to the normal line-to-line voltage in the event of a single line-to-ground fault. For double line-to-ground faults the voltages from the sound phase to ground will be less than for a single line-to-ground fault. If the ground-fault neutralizer system is out of tune, there will be some increase in the voltage to ground on the sound phase, depending upon the constants of the system and the departure from the tuned condition.

(*c*, *d*, *e*). *Impedance-Grounded Systems.* When power systems are grounded, the layouts are normally made to provide a ground-fault current which is greater than the zero-sequence charging current for normal line-to-neutral voltage on the zero-sequence network. This, of course, is done to provide sufficient current to secure positive relay action on ground faults, which is one of the principal advantages of the grounded-neutral system. When power systems are laid out in this manner, the systems generally have positive or inductive reactance from line to ground in the zero-sequence network when viewed from the fault location. This is in contrast to the negative or capacitive reactance in the zero-sequence network for the isolated-neutral system. For all impedance-grounded systems, including resistance, reactance, and solidly grounded systems, it is practical to estimate the overvoltages from sets of curves[6,8,9,11] which give the maximum line-to-ground voltage for various ratios of R_0/X_1 and X_0/X_1 for single and double line-to-ground faults.

When fault resistances are of an appreciable magnitude, their effect on the overvoltages must be taken into account.[34] Fault resistance will in some cases increase and in other cases decrease the maximum line-to-ground voltages at fundamental frequency. Curves[8,11] are available which take into account the overvoltages which are plotted on the basis of the value of fault resistance giving the highest overvoltage. When fault re-

sistances are of important magnitude, it is necessary to select the points between which the overvoltages are to be considered. If tower-footing resistance or ground resistance at the point of fault is high, it may be necessary to distinguish between the voltages from unfaulted to faulted conductor and from unfaulted conductor to ground. Thus, for protector tubes, the important overvoltage during fault may differ from the important overvoltage for an arrester application, because in one case the fault is to the protective apparatus ground and in the other case it may not be.

Sometimes it is desirable to obtain only an indication of a ground on a system. For this purpose, a potential transformer may be connected between an available neutral point and ground, or three transformers may be connected in wye with the neutral point grounded, the secondaries being connected in wye or broken delta. The latter connection is sometimes also used for metering or relaying. Either method would fall in the class of high reactance grounding. In addition the latter method leads to the possibility of another type of overvoltage known as "neutral inversion," unless suitable means for stabilizing are employed.[36]

Transient Overvoltages on Simple Circuit Changes

The application of a ground fault to a normally balanced three-phase power system gives rise to changes in the fundamental-frequency voltage as discussed in the preceding section. In addition, there is a transient voltage produced by the circuit change which is frequently taken as the difference between the initial and final fundamental voltage. This conception is accurate for a simple circuit without loss. The overvoltages will, in general, be less than these values because of decrement and because of the resolution into oscillating components of different frequencies. However, if the change in fundamental-frequency voltage is known, the natural-frequency overvoltage superposed on the fundamental frequency can be estimated, thus providing a method of evaluation sufficient for most practical cases.

Ground Faults on Unbalanced Systems

If a power system is unbalanced with respect to ground, because of either series impedances or shunt admittances, there will be a tendency to increase the voltages on some phases and to decrease them on others. If these unbalances occur at the same time as ground faults, the voltages to ground may be importantly increased.[7] These double unbalances frequently arise as the result of a ground fault, such as may be produced by

1. A conductor breaking with grounding of the broken conductor.
2. Fuse blowing.
3. The opening of one breaker pole ahead of the others.

Such conditions may produce very high voltages to ground under conditions which would give relatively low voltages if the open-phase condition did not exist at the time of a ground fault. Sometimes the system provides a parallel resonant path from the conductors of other than the open phase through the shunting paths to the open conductor beyond the phase break to ground. Under these conditions excessively high voltages may be produced by resonance action at fundamental frequency. Each of these cases must be investigated individually, and it is not practical to set up general curves for the determination of the magnitude of system overvoltages that occur under these double unbalances. The calculation of the overvoltage for a particular case of double unbalance can be carried out by the use of the method of symmetrical components, using one of the equivalent networks for simulating the double unbalances.

Complex Circuit Changes Through Arcing Paths

Circuit changes through arcing paths may give rise to system overvoltages, either as a result of

1. Forcing current zero.
2. Restriking through the previously conducting path.

These phenomena give rise to additional transients, because of the variable resistance which is characteristic of the arc, and thus introduce additional complications in overvoltage calculations.

Forcing Current Zero

If an arcing path is rapidly deionized, there may be "forcing of current zero"[12,25] by which is meant a more rapid change of current than would occur in the circuit if certain characteristics of the arc were not present. This action produces transient voltages which increase those produced by the circuit change itself. If current is flowing through the inductive elements of the circuit at the time an arc is suppressed, there is a tendency for the current to continue, completing the circuit through shunt capacitances, thus greatly increasing the voltages across them.

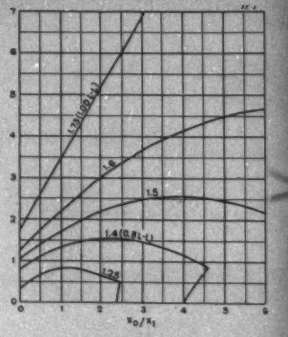

Figure 2. Line-to-ground sustained voltage chart for grounded systems, in the region of small X_0/X_1 and R_0/X_1

Figures on curves are times normal line-to-neutral voltage. In parentheses are given times line-to-line voltage for two significant values. Curves are for $X_2 = X_1$ and $R_1 = R_2 = 0$

The rate of increase of voltage and the magnitude reached depend upon the current at the time of sudden interruption, the inductance and capacitance of the circuit elements, and the dielectric strength that can be established. Such voltages can be calculated for simple circuits from the stored energy relation $LI^2 = CE^2$, using for I the value of current at the instant of sudden interruption. If considerable current is flowing and the inductance is relatively high, the transient overvoltage produced by forcing the current zero will be very large if the shunt capacitance is small. From a practical point of view, the overvoltage which may be impressed on a circuit as a result of forcing of current zero is usually limited in an arcing path because of its dielectric characteristics. The arcing path cannot instantly change from (1) low resistance corresponding to heavy current flow to (2) high dielectric strength at a very short time after the suppression of current flow. If restriking takes place, transient overvoltages may be built up or limited as discussed subsequently under the subject of "restriking".

Arcing paths in air over insulator strings and apparatus bushings rarely result in important overvoltages as a result of the forcing of current zero. However, forcing of current zero may take place in circuit breakers of either the air or oil type because of the means used to deionize the arc path rapidly. Failure of solid types of insulation may force current zero because of the high pressure built up in the fault path. In this connection it is, of course, pertinent to re-

Table I. Comparison of Various Methods of Power-System Grounding

	Isolated Neutral	Ground-Fault Neutralizer	Reactance Grounded*	Resistance Grounded	Solidly Grounded ($\frac{X_0}{X_1} < 3.0$ and $\frac{R_0}{X_1} < 1.0$ by Definition)
1. Overvoltage	Highest	Satisfactory	Satisfactory (Opinions range for generator bus from 3 to 10 and for transmission system from 3 to 40 for X_0/X_1)**	Good if neutral resistance does not exceed ground fault neutralizer ohms	Lowest
2. Ground-fault current	Very low	Negligible	Limited	Low	Highest, but seldom appreciably larger than the 3-phase short circuit current. Limit is 150 per cent of 3-phase value
3. Relaying	Difficult in most cases	Transitory line-to-ground faults are self-clearing. Relaying of other faults is satisfactory	Good	Good for low values and satisfactory for high values	Good
4. Protective level	Highest	Same as for isolated neutral	Same as for isolated neutral or better	Same as for isolated neutral or better	Lowest

* Exclusive of systems that can be classified as solidly grounded.

** Applications in the higher range may require special study.

member that, when pressure has been dissipated in this fault path, the dielectric strength is reduced below its normal value.

The interruption of current in a circuit breaker in forcing current zero is conveniently analyzed in terms of extinction voltage.[14,17] By extinction voltage is meant the voltage that appears across a circuit breaker at the end of the last half-cycle of current flow; it includes the increases in arc voltage and the increases resulting from diversion of current to shunting paths. Extinction voltages are usually relatively low but may approach the normal circuit voltage. The effect of the extinction voltage is to increase the magnitude of the transient overvoltage by an amount that is approximately equal to the extinction voltage itself.

Restriking Arcs

When current flows through any arcing path in a power system, there is a tendency for the arc to go out at every current zero and to restrike immediately or within a slight interval after normal current zero. In some cases the current is interrupted at current zero, and there is a definite "current pause" before current flow is re-established following a restrike through the arc path. This interval may be in microseconds or may last for a half-cycle of the fundamental frequency of the circuit or longer before restriking takes place.

Re-establishment of arc voltage across an arc path is controlled by the characteristic of system recovery voltage that is impressed across the arc path and tends to cause dielectric breakdown and the dielectric recovery characteristic of the arc path. If the dielectric recovery strength is at all times greater than the transient recovery voltage, then restrike will not take place. The magnitude of the resultant transient overvoltage is, therefore, greatly affected by those system characteristics that control the shape of the transient recovery voltage-time curve of the system and by the dielectric voltage-time curve of the arc path. If the arc path is of certain characteristics, restriking will take place at substantially the same potential under all conditions. Under other system transient recovery voltage and dielectric recovery characteristics, breakdown may occur under conditions for the arcs to produce cumulative oscillations[12,13] resulting in high voltage across the arcing path.

Analysis by Means of Miniature-System Setups

The preceding discussion has shown the difficulty of analyzing the effects of arcs in increasing transient voltages as a result of either forcing of current zero or as a result of restriking. In fact, the only practical method[16,18,19] available for the laboratory study of such problems is by the use of a miniature power system which is set up to simulate the actual system and which is subjected to corresponding circuit changes. In this method the various circuit elements are set up to have the corresponding positive-, negative-, and zero-sequence series impedances and shunt admittances. Distributed circuit elements, such as a transmission line, are simulated by equivalent circuits of lumped or semidistributed constants. The characteristic of the arc path can be simulated, or the arc path can be re-established as determined by the assumed dielectric characteristic of the breaker, or, as is more frequently done, the arc can be re-established at the point on the system voltage wave which would result in the highest transient disturbances. Several restrikes are possible under some conditions. However, practically all of the voltage studies to date have assumed that the probable maximum overvoltage would be obtained as a result of two restrikes occurring at such intervals as to produce the greatest possible rate of increase in system overvoltage. In the operation of a circuit breaker many restrikes may occur in the process of opening. In this connection it is to be pointed out that unless the magnitude and time of the dielectric recovery voltage curve have just the right values to cause breakdown by system recovery voltage, the restrikes will not occur at such intervals as to produce maximum cumulative action. Frequently the transient overvoltages, which cannot be avoided on the energizing of a circuit, are comparable to the voltages produced on opening a circuit with many restrikes.

System overvoltages as a result of arcing faults to ground or arcs through switching equipment in the process of opening or closing the circuit are affected by the method of system grounding and the magnitude of the grounding impedance, because these voltages are controlled by the magnitude of the sequence-impedance constants to ground and their relation to the normal circuit impedance.

Miniature-system setups have been used for the study of transients on systems grounded in different ways.[8,16,19] These investigations of the transient overvoltages for single or double line-to-ground faults or switching operations on ground-

faulted systems show that the solidly grounded system is the best, and the isolated system is the worst. In addition, the investigations of ground-fault neutralizer systems show that

1. For arcing faults to ground that are cleared without switching, the transient overvoltages are very low.

2. For switching a grounded line, the transient voltages are comparable to those of an isolated-neutral system.*

For ground faults on reactance-grounded systems, the range of transient voltages has two minimum values corresponding to the solidly grounded system and to the ground-fault neutralizer system, and two maximum values, one corresponding to the isolated-neutral system and the other corresponding to a reactance intermediate between zero for the solidly grounded system and the ground-fault neutralizer value. With resistance-grounded systems of low ohmic value, the transient voltages approach those of the solidly grounded system, and with high ohmic values (higher than ground-fault neutralizer values), the voltages approach those corresponding to the isolated-neutral system.

Summary

The foregoing discussion of system overvoltages indicates broadly the scope and complexity of the problem. In this section of the report an attempt will be made to present as concisely as possible the relationship between system overvoltages and the method of neutral grounding.

In the preceding classification of the causes of system overvoltage (see section on causes of system overvoltage) items 1*a*, *b*, and *c* deal with phenomena which are independent of the method of system grounding.

Items 2*a*, *b*, and *c* do not lend themselves to a generalized relationship with neutral-grounding impedances. However, it can be said that the isolated-neutral system is likely to give more trouble from this source than any other type of system.

The overvoltage most frequently encountered in power system operation is that which occurs as a consequence of a fault to ground (items 3*a* and *b*). These overvoltages are definitely related to the amount of grounding impedance as indicated in Figure 1. The curves of this figure are based on the sequence series reactances X_1, X_2, X_0, the zero-sequence resistance R_0, the sequence shunt capacitances C_1, C_2, C_0, and the values of fault resistance R_f, all viewed from the point of fault. The values of negative-sequence reactance and shunt capacitance are taken, in line with conventional practice, as equal to the corresponding positive-sequence quantities, although slightly higher values of voltage would be obtained if X_2 were greater than X_1. The solid curves of Figure 1 show the sustained fundamental-frequency voltages (neglecting decrement in machine fluxes) that appear from line to ground for a single line-to-ground fault. These curves are important mainly, because they are the basis for determining arrester ratings required for a particular system. A double line-to-ground fault need not be considered generally in the practical range of system constants, since voltages to ground are less than for a line-to-ground fault except as indicated in the discussion of the curves of Figure 2. If X_0/X_1 is small and positive, sustained overvoltages resulting from faults are low when R_0/X_1 is also low.

The region in which X_0/X_1 and R_0/X_1 are both small is of considerable importance. This region has been plotted in Figure 2 in a different way[11] for the purpose of showing more clearly the effect of zero-sequence impedance upon the maximum sustained voltages to ground for any type of fault and for any value of fault resistance (in Figure 1 fault resistance was neglected for positive values of X_0/X_1). These curves are for $X_2=X_1$ and $R_1=R_2=0$. They show the maximum zero-sequence impedance ratios R_0/X_1 and X_0/X_1 for which a definite voltage will not be exceeded between any phase and ground.

The curves of Figure 2 are irregular, because they are composed of parts that represent limiting voltages on different phases or for different types of faults. Thus, assuming counterclockwise rotation in *a*, *b*, *c* order, the principal parts of the curves are arcs of circles corresponding to the voltage on phase *c* for a single line-to-ground fault on phase *a* with zero fault resistance. For parts of the 1.25 and 1.40 curves near the R_0/X_1 axis, the effect of introducing fault resistance is to increase the voltage on phase *c*. For the 1.25 and 1.4 curves the portions between the X_0/X_1 axis and the points of abrupt change in the curves are determined by the voltage on phase *b*, for a single line-to-ground fault on phase *a* with the fault resistance such as to give maximum voltage. Part of the 1.25 curve near the X_0/X_1 axis is determined by the voltage on phase *a* for a double line-to-ground fault on phases *b* and *c*.

With reference to Figure 1 again, it is evident that sustained overvoltages can be very high if the ratio X_0/X_1 is in the vicinity of -2. However, this is of little practical significance, since systems would not normally operate with such constants. Most systems normally operated with isolated neutral (X_0/X_1 negative) would have a negative value of X_0/X_1 greater than 40. Consequently the region of highest voltages would not be of importance except possibly during a system disturbance in the course of which a large portion of generating capacity is lost, or the major neutral grounding points are separated from the system as a result of switching.

Isolated neutral systems have negative values of the ratio X_0/X_1 which usually are in the range between -40 and minus infinity. From Figure 1 it will be seen that for a ground fault the fundamental-frequency sustained voltage from line to ground equals 1.73 times line-to-ground voltage for the ratio of X_0/X_1 equal to minus infinity, and, that as the ratio is decreased to -40, the voltage increases to about five per cent above this value. For ground faults on isolated-neutral systems the effect of fault resistance (item 3*b* in the previous classification) causes further increase in the voltages to ground. The maximum sustained voltages to ground for any value of fault resistance are given in Figure 1 by the curve made up of long dashes separated by two short ones. In the application of protective devices, such as lightning arresters, this circumstance theoretically requires the use of devices with ratings higher than the emergency-rated voltage of the system. For some isolated-neutral systems this procedure is necessary. However, there exists considerable experience on many isolated-neutral systems with lightning arresters of ratings equivalent to the emergency-rated circuit voltage. The damage to the arrester resulting from this practice has usually been negligible, and it is probably more economical to take the risk of an occasional lightning-arrester failure from this cause than to apply arresters of higher rating.[10,11]

When a fault suddenly occurs on one phase of a system, a transient voltage occurs on the other phases. The maximum transient voltage depends on the ratio of C_1/C_0, system configuration, the amount of reactance in the circuit (X_0/X_1), the amount of resistance in the circuit (R_0/X_1), and the instant at which the fault occurs relative to the voltage wave, a particular instant being required to give the maximum disturbance. The

* This of course does not apply when the ground-fault neutralizer is short-circuited before switching is done.

effects of these factors are indicated in Figure 1, and from them an estimate can be made of the maximum transient voltage that can be obtained for most system operating conditions. The curves in Figure 1 made up of long dashes separated by one short dash are for $R_0/X_1=0$. In particular, it should be noted that as C_0 increases relative to C_1, the maximum transient voltage increases. In most cases C_1 will be greater than C_0, however.

Zero-sequence resistance (R_0/X_1) is seen to be helpful in reducing these transient oscillations. Curves for $C_1=C_0$ and for various ratios of R_0/X_1 are shown as a series of short dashes in Figure 1. While no curves are shown for values of R_0/X_1 other than zero for positive values of X_0/X_1, any resistance will tend to reduce the overvoltage from the maximum values shown for $R_0/X_1=0$.

Items 3*c*, *d*, and *e* do not lend themselves to generalized summarizing, such as shown by the curves for items 3*a* and *b*. Any of these items may be present to a certain degree and may in some cases add considerably to the amount of overvoltage shown by the curves of Figures 1 and 2.

Switching operations collectively (item 4) cannot be related definitely to system-grounding impedances. The isolated-neutral system on the one extreme is subject to the highest switching surges, while the solidly grounded system on the other extreme is subject to the lowest switching surges, generally speaking. Studies of particular systems and particular switching operations have been made, and these are helpful in pointing to circuit conditions and methods of grounding to be avoided. Certain values of neutral grounding reactance have been shown to give rise to high transient voltages during switching.[16–19] Relatively high values of neutral grounding resistance are permissible without encountering dangerous overvoltages.[17,19] In cases for which the published results are not sufficiently indicative, it is recommended that further detailed studies be made. In many cases, the *probability* of occurrence may be small, although the *possibility* of getting destructive voltages of the types classified earlier in this report may actually exist.

Of the influences listed under item 5, only "(*c*). Electrostatic charging of ungrounded systems by wind-borne particles, . . ." is recognized generally as a function of grounding impedance. Cases in which conduction or induction is a recognized cause should be studied individually.

It should be evident that it is not possible to specify any specific number of ohms of resistance or reactance as being adequate for grounding and for eliminating the possibility of all overvoltages, since the magnitude and arrangement of other system constants is directly involved. However, it is possible to limit the overvoltages and thus protect apparatus by means of lightning arresters. Arresters respond to voltage and make no distinction as to whether the cause is lightning or a switching operation. In any case, a voltage protective level is held. In the case of a sufficiently low grounding impedance, permitting the use of grounded neutral rating arresters, this protective level is substantially lower than for higher grounding impedance requiring the ungrounded rating arrester. Consequently there is a gain, from the standpoint of lowering the protective level, in selecting grounding impedances of low ohmic value. However other considerations, such as limitation of short-circuit currents for power-system operating reasons or for inductive coordination, may prevent taking full advantage of this possibility.

It should be emphasized that the number of grounding points is of importance also, since during a system disturbance it is undesirable to have any part of the system with connected generation to be left without a neutral ground. While in the limit, this would mean that every source of short-circuit current should have a neutral ground, practical and economic considerations may dictate a somewhat smaller number of grounding points.

Engineering opinions, as to the choice of resistance or reactance grounding and the proper ohmic value, have not crystallized. This situation results from the complexity of the problem, the intangibility of many factors involved, the range of conditions encountered, and the results to be achieved. However, it is pertinent in connection with this discussion to consider the effect of such factors in the grounding problem as relative dielectric strength of apparatus, current limitation requirements, relaying requirements, and lightning-arrester settings, since they affect the kind and magnitude of grounding impedances.

Many engineers prefer to ground directly all available neutral points, introducing neutral reactance where necessary to avoid increasing machine stresses and breaker ratings on ground faults beyond the values corresponding to three-phase short-circuit currents. This procedure comes within the classification of solidly grounded systems with $X_0/X_1<3$. Other engineers prefer to introduce greater limitation of fault current, which is generally accomplished by neutral resistors. The problems are different for grounding transmission systems through transformers than for grounding generator busses because of the relatively lower dielectric strength of rotating machines. In general, the transient overvoltages with resistance grounding are more favorable than with moderate values of reactance grounding, and the maximum value of resistance which may be used is generally considered to be that which corresponds to the tuned reactance value of the ground-fault neutralizer. The maximum permissible value of reactance grounding is considerably more speculative, and discussions have not reached a conclusion. The permissible value of the ratio X_0/X_1 is affected by the extinction voltage, the sequence series reactance and sequence shunt capacitance constants of the system, since they affect the conditions for which a high-frequency current zero may be obtained and thus control the conditions for restriking. Engineering opinion on the maximum permissible value of X_0/X_1 ranges from 3 to 10 for generator grounding. For grounding transmission systems, higher ratios of X_0/X_1 have been considered, ranging from 10 to 40, the highest values having been considered for grounding transformers applied to transmission circuits with aerial lines. Applications in this range however may require special study. Sometimes resistors in parallel with neutral reactors have been used, with the reactor to limit ground current and the resistor to limit transient voltages.

Table I lists in a very general way the advantages and disadvantages of various methods of system grounding.

Classification of Power Systems With Respect to Method of Grounding

The preceding discussion has shown that, from the standpoint of overvoltages at least, the various methods of grounding power systems may be classified according to ground connections and sequence impedance constants* as follows:

1. *An isolated-neutral (ungrounded) system* is a system without an intentional connection to ground. Isolated-neutral systems may be subjected to various overvoltages, depending upon the ratio of X_0/X_1 as viewed from the fault location.**

* R_0, X_0, and X_1 are, respectively, the zero-sequence resistance, the zero-sequence reactance taken as positive if inductive and negative if capacitive, and positive-sequence subtransient reactance. All these impedances are those of the system as viewed from the fault location.

** A system grounded through potential transformers is not an isolated-neutral but a reactance-grounded system, according to this classification.

2. *A grounded system* is a system in which at least one conductor or point (usually the middle wire or neutral point of transformer or generator windings) is intentionally grounded, either solidly or through impedance. Grounded systems may be subjected to various overvoltages, depending upon the ratios of X_0/X_1 and R_0/X_1 as viewed from the fault location.

3. *A solidly grounded system or portion of a system* is a system or specified portion thereof that has for all fault locations zero- to positive-sequence ratios of $X_0/X_1 < 3$ and $R_0/X_1 < 1$ for any condition of operation and amount of connected generator capacity.[9,10,11,20]

4. *A resistance-grounded system* is a system grounded through an impedance, the principal element of which is resistance.

5. *A reactance-grounded system* is a system grounded through an impedance, the principal element of which is reactance.

6. *A ground-fault neutraliser system* is a system grounded by means of a grounding device which provides an inductive reactive component of current in a ground fault that is substantially equal to, and therefore neutralizes, the rated frequency capacitive component of the ground-fault current.

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Equivalent Circuits for Oscillating Systems and the Riemann–Christoffel Curvature Tensor

GABRIEL KRON
ASSOCIATE AIEE

Synopsis: Many electromechanical systems that are being studied in connection with the war effort have so many degrees of freedom that it is totally impractical to analyze their performance by direct calculation. It is, therefore, increasingly important to develop equivalent circuits for these multiple oscillating systems, that can be put on the a-c calculating board and so solved by direct reading of instruments.

In this paper it is shown that a necessary (though not sufficient) condition for the existence of a physical model, corresponding to a given set of equations, is that the set should be a tensor equation. This follows from the fact that only quantities that are tensors can be measured by instruments. The conclusion is therefore reached that only equations that are in tensor form can be set up on the a-c calculating board.

The principle is illustrated by setting up equivalent circuits with the aid of tensorial hunting equations for the determination of the steady-state, hunting, and self-excitation performance of two interconnected instrument-Selsyns, of two salient-pole synchronous machines, and of a capacitor-compensated transmission line connected to a salient-pole synchronous machine. A companion paper, "Self-Excited Oscillations of Capacitor-Compensated Long-Distance Transmission Systems"[13] contains the results of an extended study made on the a-c network analyzer with the aid of one of the equivalent circuits developed here.

Difficulties in Establishing Equivalent Circuits for Hunting

IN trying to set up equivalent stationary networks for the *hunting* performance calculation of interconnected systems, it was found to be impossible to establish networks that correspond to the equations of the systems, even though the latter were sets of linear algebraic equations of the form $e = Z \cdot i$. All known methods of tranformation of reference frames or of variables led to expressions that could not be measured by instruments.

The apparently insurmountable difficulties were finally overcome by the following reasoning:

The equations of small oscillation under consideration were the standard Lagrangean equations of motion, in which x^m was replaced by $x^m + \Delta x^m$ as is the universal custom. It is however well known that, while the Lagrangean equations are tensor equations, the equations of small oscillations, derived from the former by standard methods, are no longer tensor equations. Since a tensor is a measurable physical entity, it seems plausible that the standard equations of hunting do not show correctly the physics of the problem—even though they do give correct numerical answers—nor do they express the hunting phenomena in terms of measurable quantities. Hence, no physical model corresponding to a set of non-tensor equations may exist.

The tensorial form of the equations of small oscillations of electrical machinery already has been established[8]. These tensor equations differ from the standard equations by having certain terms added to and subtracted from the latter. In other words, if the standard hunting equations are expressed as

$$A + B = 0$$

(where none of the sets of expressions A or B nor the combination $A+B$ are tensors), the tensorial hunting equations may be expressed as

$$A + B + C - C = 0$$

where C represents a set of expressions, that otherwise would cancel.

Now while neither A nor C are tensors, the combination $A+C$ is a tensor, so is the combination $B-C$. Hence each expression in the equation

$$(A + C) + (B - C) = 0$$

is a tensor. Therefore $A+C$ must be a measurable quantity and so must $B-C$.

If the reasoning is valid then this last equation and not the simplified equation must be the proper physical form, that admits an equivalent circuit. If C is cancelled, then the resultant equation still would give correct numerical answers, though it would represent an incomplete physical picture, hence a physically unrealizable equivalent circuit.

This reasoning proved to be correct in every detail. When the additional terms C were calculated, the equivalent circuit of the oscillating system followed immediately and in a perfectly straightforward manner.

In machines for which the standard hunting equations did give an equivalent circuit outright, the terms A and B each were already tensors (measurable quantities) because of the simplicity of the physical system. Hence the hunting equation itself $A+B=0$ was already a tensor equation.

The First Principle of the General Theory of Relativity

In 1905 Einstein came forward with the special theory of relativity. One of the consequences of this theory is the postulate that the three co-ordinates of space x, y, z, and time t are not two distinct physical entities

$x^m =$

m	1	2	3
	x	y	z

$\quad t =$

t

but are components of a single tensor, a single physical entity

$x^\alpha =$

α	1	2	3	4
	x	y	z	jct

With this assumption it could be shown, for instance, that the separate electric and magnetic fields were only components of one underlying physical reality, the electromagnetic field. (Namely, $B = B_\alpha$ and $H = H^\alpha$ are components of one tensor $F_\alpha{}^\beta$.)

In 1916 Einstein announced the general theory of relativity. One of the outgrowths of this more general theory is the postulate that both the gravitational and the electromagnetic fields are components of only one underlying physical reality. The first principle of this theory may be formulated for the present purpose as follows:[1]

"All laws of nature are tensor equations"*

For instance, the equations of Lagrange are tensor equations; so are the field equations of Maxwell in special reference frames. For more general reference frames Maxwell's equations have been brought into tensorial form by Minkowsky.

The question whether the group of transformations under which the laws of

Paper 43-9, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted October 10, 1942; made available for printing November 6, 1942.

GABRIEL KRON is consulting engineer, General Electric Company, Schenectady, N. Y.

* "Die allgemeinen Naturgesetze sind durch Gleichungen auszudrucken, die für alle Koordinatensysteme gelten, d.h. die beliebigen Substitutionen gegenüber kovariant (allgemein kovariant) sind."

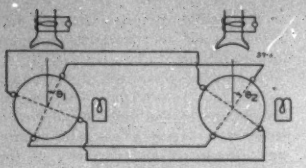


Figure 1. Two single-phase instrument Selsyns

nature are invariant is the Lorentz group (as postulated by Einstein), or the Galilean group, has no bearing upon the argument of this paper.

A Principle to Establish Models for Physical Systems

Of course not only the grandiose differential equations that describe the curvature of light as it passes near the sun are tensor equations, but also the simple linear differential or algebraic equations that represent the performance of such a lowly creation as a stationary network. Hence if a stationary network is given, and its set of linear algebraic equations $e = Z \cdot i$ is established by Ohm's and Kirchhoff's laws, the set always comes out as a tensor equation.

But let now the problem be reversed. Let a set of linear algebraic equations $e = Z \cdot i$ be given: Are or are they not the equations of a stationary network? In other words, is it possible to establish a physical model whose performance corresponds term by term to the given set of equations?

Table I. Torque Formulas of Two Instrument Selsyns
Valid If Either Machine Hunts

(a). Steady-State Torques

$$i^f E_{f1}^* = W_1 \qquad i^f E_{f2}^* = W_3 \qquad T_1 = W_1 + W_3$$
$$i^b E_{b1}^* = W_2 \qquad i^b E_{b2}^* = W_4 \qquad T_2 = W_2 + W_4$$

(b). Damping and Synchronizing Torques of the Second Machine (Receiver)

$$i^f \Delta E_{f1}^* = W_5 + jQ_5 \qquad i^b \Delta E_{b2}^* = W_7 + jQ_7 \qquad T_{s2}' = \frac{W_5 + W_6 + W_7 + W_8}{2}$$

$$\Delta i^f E_{f1}^* = W_6 + jQ_6 \qquad \Delta i^b E_{b2}^* = W_8 + jQ_8 \qquad T_{d2}' = \frac{(Q_6 + Q_8) - (Q_5 + Q_7)}{2h}$$

Repeat the same measurements with $-h$ hunting network.

$$T_{s2} = T_{s2}' + T_{s2}'' \qquad T_{d2} = T_{d2}' - T_{d2}''$$

(c). Damping and Synchronizing Torques of the First Machine (Transmitter)

$$i^f \Delta E_{f1}^* = W_9 + jQ_9 \qquad i^b \Delta E_{b1}^* = W_{11} + jQ_{11} \qquad T_{s1}' = \frac{W_9 + W_{10} + W_{11} + W_{12}}{2}$$

$$\Delta i^f E_{f1}^* = W_{10} + jQ_{10} \qquad \Delta i^b E_{b1}^* = W_{12} + jQ_{12} \qquad T_{d1}' = \frac{(Q_{10} + Q_{12}) - (Q_9 + Q_{11})}{2h}$$

Repeat the same measurements with $-h$ hunting network.

$$T_{s1} = T_{s1}' + T_{s1}'' \qquad T_{d1} = T_{d1}' - T_{d1}''$$

In consequence of the first principle of general relativity, it is safe to conclude that a primary and necessary condition for the establishment of a model is that the set of equations should be a tensor equation. If it is not a tensor equation, then the set definitely cannot represent any physically existing structure, such as a stationary network.

This deduction was rather emphatically proved in attempting to establish equivalent circuits by use of the nontensor hunting equations $e = Z \cdot i$.

This simple fact may be generalized to include all physical phenomena by the following principle:

"A set of equations, representing the performance of any physical system (be it mechanical, electrical, thermal, or any other system) may be represented by a physical model (equivalent circuit) only if the set of equations is a tensor equation."

Even if no model of a system is built, the engineer is interested in the objects that he can measure. Or if he does not care to measure certain quantities, he may still be interested in a mental "physical picture" of the phenomena taking place in the various parts of the system. As a corollary of the above principle it may be stated that:

"In order that a set of equations should express the performance of a physical system in terms of measurable and visualizable quantities, the set of equations must be a tensor equation."

Examples of sets of nontensor equations are those that represent small oscillations of dynamical systems, if these equations

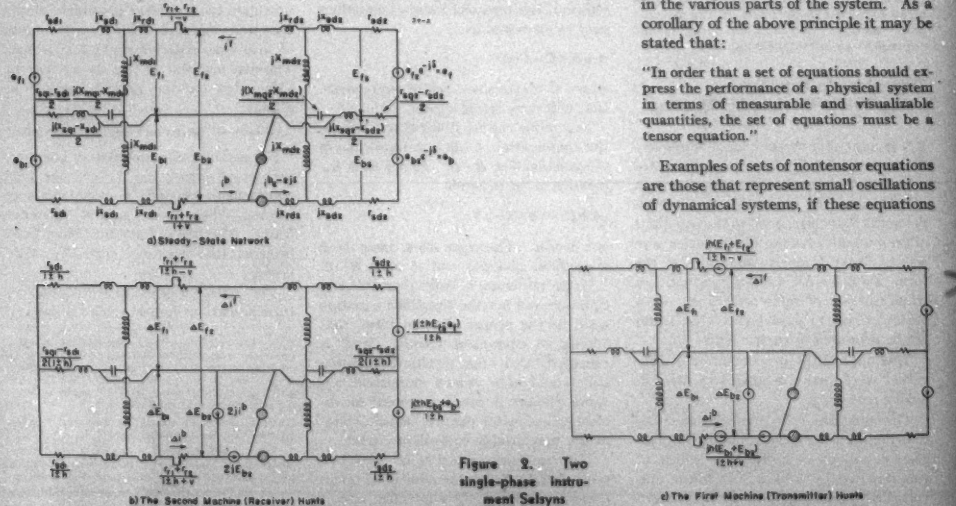
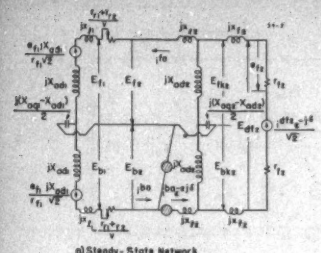
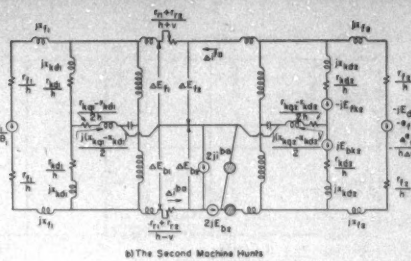


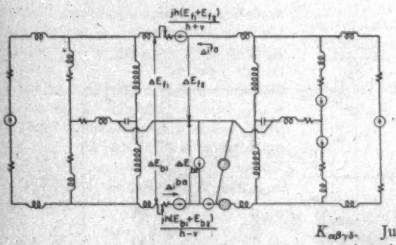
Figure 2. Two single-phase instrument Selsyns



a) Steady-State Network



b) The Second Machine Hunts



c) The First Machine Hunts

Figure 3. Two salient-pole synchronous machines

are derived from the equation of Lagrange by standard methods. Other nontensor equations are those of magnetrons, ultra-high-frequency tubes, and so forth, in the analysis of which small variations are taken in Maxwell's equations.

Many of the theories used in electrical engineering for the study of rotating machines and stationary networks are also nontensor equations. Such theories are usually valid for one particular machine and even then only for one particular reference frame. In contrast with these in Park's analysis of the synchronous machine, all basic equations (except those of hunting) may be shown to be tensor equations, and to this very fact their success must be attributed. Fortescue's method of symmetrical components is a tensorial transformation; hence its value and permanence.

The conclusion of the reasoning is that even though a set of linear algebraic equations $e = Z \cdot i$ is available, it does not follow that an equivalent stationary network can be established for it. A necessary (though not sufficient) condition is that the equation should be a tensor equation. If it is not, then it cannot correspond term by term to any physically realizable network.

The change of a set of linear algebraic equations $e = Z \cdot i$ into a tensor equation consists—in the present case when it represents small oscillations—of the introduction of such tensorial concepts as the Riemann–Christoffel curvature tensor $K_{\alpha\beta\gamma\delta}$. Just how to change a set of equations into a tensor equation always depends on what the equations represent physically. The equations of each type of physical phenomenon require separate treatment.

The Affine Connection

The most general form of connection used in affine differential geometry and also in the study of electrical machinery is

$$\Gamma_{\alpha\beta,\,\gamma} = \frac{1}{2}\left(\frac{\partial a_{\beta\gamma}}{\partial x^{\alpha}} + \frac{\partial a_{\gamma\alpha}}{\partial x^{\beta}} - \frac{\partial a_{\alpha\beta}}{\partial x^{\gamma}}\right) - \Omega_{\alpha\beta,\,\gamma} + \Omega_{\gamma\beta,\,\alpha} + \Omega_{\gamma\alpha,\,\beta} + S_{\alpha\beta\gamma} - S_{\gamma\beta\alpha} - S_{\gamma\alpha\beta} + \frac{1}{2}(Q_{\alpha\beta\gamma} + Q_{\beta\gamma\alpha} - Q_{\gamma\alpha\beta}) \quad (1)$$

where

$S_{\alpha\beta\gamma}$ = torsion tensor, skew-symmetric in α and β

$Q_{\alpha\beta\gamma}$ = "Weyl tensor," symmetric in α and β

$\Omega_{\alpha\beta,\,\gamma}$ = nonholonomic object, skew-symmetric in α and β

In the special types of electrical machines considered in this paper the Weyl tensor $Q_{\alpha\beta\gamma}$ is zero.

In the dynamical equations of Lagrange $\Gamma_{\alpha\beta,\,\gamma}$ is always multiplied by $\dot{x}^{\alpha} = i^{\alpha}$ twice, as $\Gamma_{\alpha\beta,\,\gamma} i^{\alpha} i^{\beta}$. As a consequence some of the above terms cancel or become equal, so that the affine connection simplifies to

$$\Gamma_{\alpha\beta,\,\gamma} = \left(\frac{\partial a_{\beta\gamma}}{\partial x^{\alpha}} - \frac{1}{2}\frac{\partial a_{\alpha\beta}}{\partial x^{\gamma}}\right) + 2\Omega_{\gamma\alpha\beta} - 2S_{\gamma\alpha\beta} = [\alpha\beta,\,\gamma] - 2S_{\gamma\alpha\beta} \quad (2)$$

where $[\alpha\beta,\,\gamma]$ is the *nonholonomic* Christoffel symbol.

It is emphasized that the above simplified form of $\Gamma_{\alpha\beta,\,\gamma}$ can be used only in the equation of motion and in its variations, such as the equations of small oscillations. In any other equation, such as the field equations of Maxwell, the complete form of $\Gamma_{\alpha\beta,\,\gamma}$, as it appears in equation 1 must be used.[9]

The Three Types of Transformations

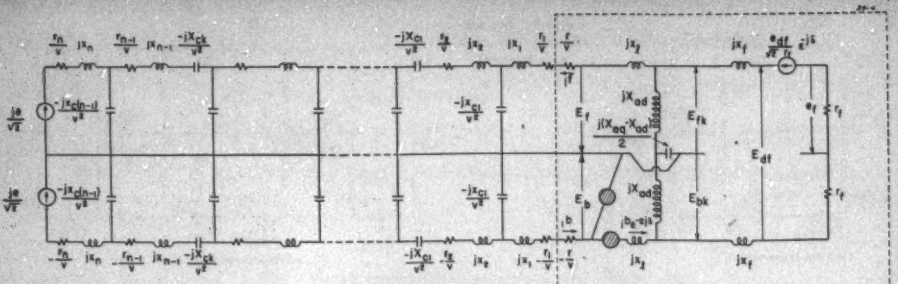
In establishing equivalent networks for electrical machines there are at least three types of transformations used:[2]

1. Co-ordinate transformations.

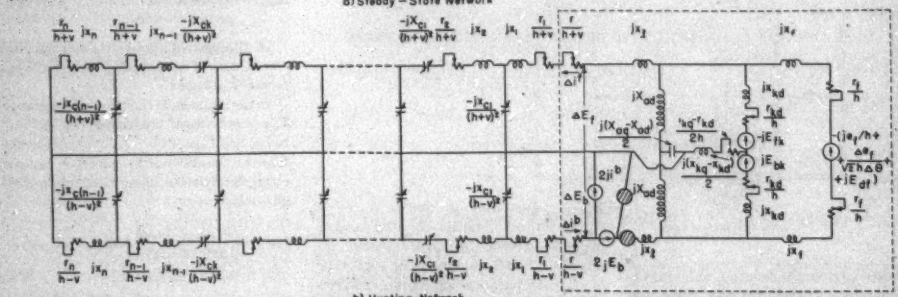
Table II. Torque Formulas of Two Synchronous Machines

Valid If Either Machine Hunts

Steady-State Torques	Damping and Synchronizing Torques	
First Machine	**First Machine**	**Second Machine**
$i^{fa}E_{f1}{}^{*} = W_1$	$i^{fa}\Delta E_{f1}{}^{*} = W_1 + jQ_1$	$i^{fa}\Delta E_{f2}{}^{*} = W_9 + jQ_9$
$i^{ba}E_{b1}{}^{*} = W_2$	$\Delta i^{fa}E_{f1}{}^{*} = W_8 + jQ_8$	$\Delta i^{fa}E_{f2}{}^{*} = W_{10} + jQ_{10}$
$T_1 = W_1 + W_2$	$i^{ba}\Delta E_{b1}{}^{*} = W_7 + jQ_7$	$i^{ba}\Delta E_{b2}{}^{*} = W_{11} + jQ_{11}$
	$\Delta i^{ba}E_{b1}{}^{*} = W_6 + jQ_6$	$\Delta i^{ba}E_{b2}{}^{*} = W_{12} + jQ_{12}$
Second Machine		
$i^{fa}E_{f2}{}^{*} = W_3$		
$i^{ba}E_{b2}{}^{*} = W_4$	$T_{s1} = -(W_5 + W_6 + W_7 + W_8)$	$T_{s2} = -(W_9 + W_{10} + W_{11} + W_{12})$
$T_2 = W_3 + W_4$	$T_{d1} = \frac{(Q_5 + Q_7) - (Q_6 + Q_8)}{h}$	$T_{d2} = \frac{(Q_9 + Q_{11}) - (Q_{10} + Q_{12})}{h}$



a) Steady – State Network



b) Hunting Network

Figure 4. Transmission line with series capacitors connected to salient-pole synchronous machine

All reference axes rotate uniformly with the infinite bus

2. Spin transformations.
3. Gauge transformations.

Co-ordinate transformations are used in passing from the stationary a, b, c axes to the rotating d, q, o axes or in interconnecting the reference axes. Spin transformations are employed in introducing the hypothetical symmetrical component frame. Gauge transformations enter in eliminating some of the phase shifters that would otherwise appear in the equivalent circuits.

In consequence of all these necessary transformations, the theories of spinor analysis must be resorted to, in addition to those of tensor analysis.

Table III. Torque Formulas of Synchronous Machine Connected to Transmission Line

Steady-State Torques	Damping and Synchronizing Torques		
$i^f E_f^* = W'$	$i^f \Delta E_f^* = W_1 + jQ_1$	$\Delta i^f E_f^* = W_3 + jQ_3$	$T_s = W_1 + W_3 + W_4 + W_4$
$i^b E_b^* = W''$	$i^b \Delta E_b^* = W_2 + jQ_2$	$\Delta i^b E_b^* = W_4 + jQ_4$	$T_d = \dfrac{(Q_3 + Q_4) - (Q_1 + Q_2)}{h}$
$T = W' + W''$			

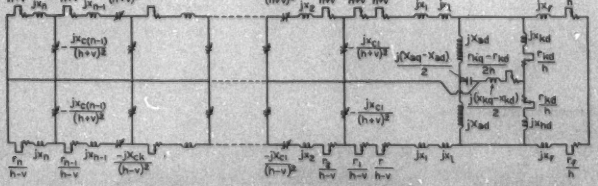


Figure 5. Self-excitation network of the transmission system (mass = infinite)

Spinor Form of the Equation of Motion

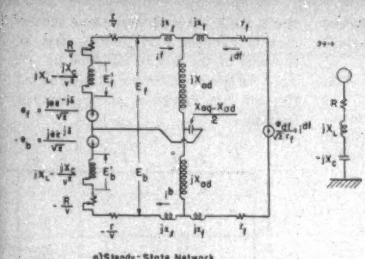
When the components of $\Gamma_{\alpha\beta,\,\gamma}$ contain complex numbers or complex functions, it has been shown[8] that eight different $\Gamma_{\alpha\beta,\,\gamma}$ may occur in the most general case, namely $\Gamma_{\alpha\beta,\,\gamma}$, $\Gamma_{\alpha\bar{\beta},\,\gamma}$, $\Gamma_{\bar{\alpha}\beta,\,\gamma}$ $\Gamma_{\bar{\alpha}\bar{\beta},\,\gamma}$ and their conjugates. It has been found by the writer that in the Lagrangean equation, or at least in electrical machinery, six of the above eight expressions are zero, and only the following two have nonzero components, $\Gamma_{\alpha\beta,\,\gamma}$ and $\Gamma_{\bar{\alpha}\bar{\beta},\,\gamma}$. In particular it was found, that of the two components of $\Gamma_{\alpha\beta,\,\gamma}$ namely

$$\Gamma_{\alpha\beta,\,\gamma} \triangleq [\alpha\beta,\,\gamma] - 2S_{\gamma\alpha\beta} \qquad (3)$$

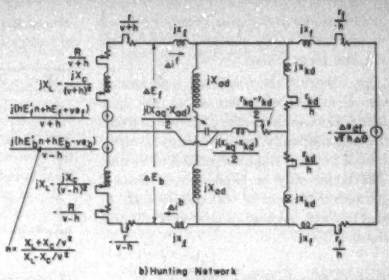
the nonholonomic Christoffel symbol $[\alpha\beta,\,\bar{\gamma}]$ has only its free index barred, while the torsion tensor $S_{\alpha\bar{\beta}\gamma}$ has its skew-symmetric indexes both barred. Hence in interchanging α and β in the latter, the components change signs only, but do not assume conjugate values.

From this property the following conclusions may be drawn, to be used as a laborsaving device:

In analyzing electrical machinery in complex variables (for instance when sym-



a) Steady-State Network



b) Hunting Network

Figure 6. Salient-pole synchronous machine connected to infinite bus through R-L-C tie-line

metrical components are introduced or when polyphase machines are studied) the usual tensor equations containing the unbarred $\Gamma_{\alpha\beta,\,\gamma}$ may be used in all manipulations, even though the variables are complex. However when $\Gamma_{\alpha\beta,\,\gamma}$ is replaced by its component objects, then $[\alpha\beta,\,\bar{\gamma}]$ should have its free index barred and $S_{\alpha\bar{\beta}\gamma}$ its two skew-symmetric indexes.

Accordingly the equation of motion of Lagrange

$$e_\alpha = R_{\alpha\bar{\beta}} i^{\bar{\beta}} + a_{\alpha\bar{\beta}} \frac{di^{\bar{\beta}}}{dt} + \Gamma_{\beta\gamma,\,\alpha} i^{\beta} i^{\gamma} \qquad (4)$$

may be written for complex variables as

$$e_\alpha = R_{\alpha\bar{\beta}} i^{\bar{\beta}} + a_{\alpha\bar{\beta}} \frac{di^{\bar{\beta}}}{dt} + [\beta\gamma,\,\alpha] i^{\beta} i^{\gamma} - 2S_{\alpha\bar{\beta}\gamma} i^{\bar{\beta}} i^{\gamma} \qquad (5)$$

where $[\beta\gamma,\,\alpha]$ is the nonholonomic Christoffel symbol.

From this notation automatically follows for instance that in calculating the torque one of the currents must be changed to its conjugate. It should be remembered that:

1. e_α is normally barred.
2. i^α is normally unbarred.
3. The metric tensor $a_{\alpha\beta}$ is no longer symmetrical, but hermitian

$$a = a_i{}^{\alpha} \text{ or } a_{\alpha\beta} = a_{\beta\alpha} \qquad (6)$$

4. When in the transient equations the $p = d/dt$ are replaced by jw, the spin indices do not refer to these new complex numbers. For that reason p should be replaced by kw where k plays a similar role to j, still it remains distinct from it.
5. When the free index is a geometrical index s the equation represents torques. Hence only the real part of the torque equations is calculated.

The Equations of Hunting

Making small changes in the equation of motion of Lagrange (equation 4) the conventional nontensorial equation of hunting is

$$E_\alpha + \frac{\partial e_\alpha}{\partial x^\beta}\Delta x^\beta = \frac{\partial R_{\alpha\beta}}{\partial x^\gamma} i^\beta \Delta x^\gamma + R_{\alpha\beta}\Delta i^\beta + a_{\alpha\beta}\frac{d(\Delta i^\beta)}{dt} + \Gamma_{\beta\gamma,\,\alpha}\Delta i^\beta i^\gamma + \Gamma_{\beta\gamma,\,\alpha} i^\beta \Delta i^\gamma + \frac{\partial a_{\alpha\beta}}{\partial x^\gamma}\frac{di^\beta}{dt}\Delta x^\gamma + \frac{\partial \Gamma_{\beta\gamma,\,\alpha}}{\partial x^\delta} i^\beta i^\gamma \Delta x^\delta \qquad (7)$$

where E_α is any small impressed force. In the special case when $a_{\alpha\beta}$ and $\Gamma_{\alpha\beta,\,\gamma}$ are constant, the last two terms disappear, and the equation becomes a tensor equation.

The tensorial equation of small oscillations and of their geometrical analogue, the disturbed geodesic is well known.[4-7] Its derivation, when applied to electrical machinery, has been given in reference 8, equation 161 as

$$E_\alpha + \delta e_\alpha = R_{\alpha\beta}\delta i^\beta + a_{\alpha\beta}\frac{\delta(\delta i^\beta)}{dt} + K_{\delta\gamma\beta\alpha} i^\beta i^\delta dx^\gamma + R_{\alpha\beta\gamma} i^\beta dx^\gamma \qquad (8)$$

Each symbol in the equation is a tensor.

Replacing each tensor by its component geometric objects, the above equation may be written as (reference 8, equation 162):

$$\begin{aligned} E_\alpha + \delta e_\alpha &\left\{ \right| E_\alpha + \frac{\partial e_\alpha}{\partial x^\beta}\Delta x^\beta + \Gamma_{\gamma\delta,\,\alpha} e^\gamma \Delta x^\delta \\ = \delta(R_{\alpha\beta} i^\beta) &\left\{ \right| = R_{\alpha\beta}\Delta i^\beta + \frac{\partial R_{\alpha\beta}}{\partial x^\gamma} i^\beta \Delta x^\gamma + \Gamma_{\gamma\delta,\,\alpha} R^\gamma{}_{\beta i}{}^\beta \Delta x^\delta \\ + a_{\alpha\beta}\frac{\delta(\delta i^\beta)}{dt} &\left\{ \right| + \Gamma_{\gamma\delta,\,\alpha} e^\gamma \Delta x^\delta - \Gamma_{\gamma\delta,\,\alpha} R^\gamma{}_{\beta i}{}^\beta \Delta x^\delta + a_{\alpha\beta}\frac{d}{dt}\Delta i^\beta + \frac{\partial a_{\alpha\beta}}{\partial x^\gamma}\frac{di^\beta}{dt}\Delta x^\gamma + \Gamma_{\beta\gamma,\,\alpha}\Delta i^\beta i^\gamma \\ &\left\{ \right| + \Gamma_{\beta\gamma,\,\alpha} i^\beta \Delta i^\gamma + \left(\frac{\partial \Gamma_{\beta\gamma,\,\alpha}}{\partial x^\delta} + \Gamma_{\lambda\delta,\,\alpha}\Gamma_{\beta\gamma}{}^{\lambda} - \Gamma_{\lambda\gamma,\,\alpha}\Gamma_{\beta\delta}{}^{\lambda} - 2\Gamma_{\beta\lambda,\,\alpha}\Omega_{\delta\gamma}{}^{\lambda}\right) i^\beta i^\delta \Delta x^\gamma \\ + K_{\delta\gamma\beta\alpha} i^\beta i^\delta dx^\gamma &\left\{ \right| + \left(\frac{\partial \Gamma_{\beta\delta,\,\alpha}}{\partial x^\gamma} - \frac{\partial \Gamma_{\beta\gamma,\,\alpha}}{\partial x^\delta} + \Gamma_{\lambda\gamma,\,\alpha}\Gamma_{\beta\delta}{}^{\lambda} - \Gamma_{\lambda\delta,\,\alpha}\Gamma_{\beta\gamma}{}^{\lambda} + 2\Gamma_{\beta\lambda,\,\alpha}\Omega_{\delta\gamma}{}^{\lambda}\right) i^\beta i^\delta \Delta x^\gamma \end{aligned} \qquad (9)$$

The equation given in the reference is generalized here to include nonholonomic reference frames, as all examples considered below involve nonholonomic systems.

The Set to Be Added and Subtracted

The tensorial equation of hunting (9) consists of the standard equation of hunting (7) with a set of terms ΔE_α *added* and *subtracted*. The set is

$$\Delta E_\alpha = -\Gamma_{\beta\gamma,\,\alpha}(e^\beta - R^\beta{}_{\delta i}{}^{\bar{\delta}} - \Gamma_{\alpha\delta}{}^{\beta} i^\gamma i^{\bar{\delta}})\Delta x^\gamma + \left(\Gamma_{\lambda\delta,\,\alpha}\Gamma_{\beta\gamma}{}^{\lambda} + \frac{\partial \Gamma_{\beta\gamma,\,\alpha}}{\partial x^\delta} + 2\Gamma_{\beta\lambda,\,\alpha}\Omega_{\delta\gamma}{}^{\lambda}\right) i^\beta i^{\bar{\delta}} \Delta x^\gamma \qquad (10)$$

This set may be simplified by noting that by the equation of motion (4)

$$e^\beta - R^\beta{}_{\delta i}{}^{\bar{\delta}} - \Gamma_{\alpha\delta}{}^{\beta} i^\gamma i^{\bar{\delta}} = \frac{di^{\bar{\beta}}}{dt} = p i^{\bar{\beta}} \qquad (11)$$

Hence the set to be added and subtracted from the standard equations of hunting is

$$\Delta E_\alpha = -\Gamma_{\beta\gamma,\,\alpha}\frac{di^{\bar{\beta}}}{dt}\Delta x^\gamma + \left(\Gamma_{\lambda\delta,\,\alpha}\Gamma_{\beta\gamma}{}^{\lambda} + 2\Gamma_{\beta\lambda,\,\alpha}\Omega_{\delta\gamma}{}^{\lambda} + \frac{\partial \Gamma_{\beta\gamma,\,\alpha}}{\partial x^\delta}\right) i^\beta i^{\bar{\delta}} \Delta x^\gamma \qquad (12)$$

It should be noted that in electrical machinery Δx^γ must always have a geometrical index s as Δx^s, since all objects are functions only of x^s. Also in all the examples considered here, the two

machines *run at the same speed*, $x^{\alpha}=\delta_2-\delta_1$ = constant, hence $\dot{s}^{\alpha}=p(\theta_2-\theta_1)=0$, and the last term is zero.

By allowing the *free* index α to assume the electrical variables m or the geometrical variables s, the equation of hunting automatically separates into an equation of voltage and an equation of torque. The latter may be expressed in terms of geometric objects of valence two G, V, and so forth, instead of objects of valence three or four.

Tensor Form of the Voltages and Torques

1. If $\alpha=\overline{m}$, the remaining terms may be expressed as

$$\Delta E_{\overline{m}} = -\Gamma_{\beta\alpha\overline{m}}\frac{di^{\beta}}{dt}\Delta x^{\alpha}+(\Gamma_{\lambda\delta,\overline{m}}\Gamma_{\beta\lambda}+2\Gamma_{\beta\lambda,\overline{m}}\Omega_{\delta\beta}{}^{\lambda})i^{\beta}i^{\delta}\Delta x^{\alpha}$$
$$= -\Gamma_{ms,\overline{m}}p i^{m}\Delta x^{s}+2\Gamma_{\overline{k}m,\overline{m}}\Omega_{ms}{}^{n}i^{\overline{k}}i^{s}\Delta x^{s}+\Gamma_{ms,\overline{m}}\Gamma_{\overline{k}s}{}^{n}i^{\overline{k}}i^{s}\Delta x^{s}$$
$$= -V_{\overline{m}m}p i^{m}\Delta\delta-G_{\overline{m}n}L^{nr}V_{rk}i^{k}p\theta\,\Delta\delta+V_{\overline{m}n}L^{nr}V_{rk}i^{k}p\delta$$

$$\Delta E = -V\cdot pi\,\Delta\delta-G\cdot L^{-1}\cdot V\cdot ip\theta\,\Delta\delta+V\cdot L^{-1}\cdot V\cdot ip\delta \quad (13)$$

If the two machines run at the same speed $Vp\delta=0$, and the last term is zero. Hence *the additional term to the equation of voltage is* (to be added and subtracted)

$$\boxed{\Delta E=(-V\cdot pi-\mathcal{T}_i{}^{*}\cdot Vp\theta\cdot i)\,\Delta\delta} \quad (14)$$

where $\delta=\pm(\theta_2-\theta_1)$. It must be remembered that this formula is valid only if the two machines run at the same steady-state speed, $p\theta$.

2. If $\alpha=\overline{s}(\delta=s$ and $\beta=k)$

$$\Delta E_{\overline{s}}=(\Gamma_{ms,}{}_{\overline{s}}\Gamma_{\overline{k}s}{}^{m}+2\Gamma_{\overline{k}m,}{}_{\overline{s}}\Omega_{ms}{}^{m})i^{\overline{k}}i^{m}\Delta x^{s} \quad (15)$$

The first term is zero and the second term is

$$2\Gamma_{\overline{k}m,}{}_{\overline{s}}\Omega_{ns}{}^{m}i^{\overline{k}}i^{n}\Delta x^{s}=-i^{\overline{k}}G_{\overline{k}n}L^{nr}V_{rs}i^{m}\Delta\delta=-i\cdot G\cdot L^{-1}\cdot V\cdot i\,\Delta\delta \quad (16)$$

Hence *the additional term of the equation of torque is* (to be added and subtracted)

$$\boxed{\Delta T=-i\cdot\mathcal{T}_i{}^{*}\cdot V\cdot i\,\Delta\delta} \quad (17)$$

Example of Two Instrument Selsyns

In interconnecting two slip-ring induction motors, Figure 1 (or synchronous machines) running at an angle $\delta=\theta_2-\theta_1$ from each other, their equivalent circuit requires two phase shifters. One with $\epsilon^{j\delta}$ in the f_r mesh, another with $\epsilon^{-j\delta}$ in the b_r mesh. One of these phase shifters may be eliminated by rotating first all the axes of the second machine by $\epsilon^{j\delta}$. Then the two machines are interconnected (if both are expressed along sequence axes) by

$C=$

	f_1	b_1	f_r	b_r	f_2	b_2
f_{s1}	1					
f_{r1}			1			
b_{s1}		1				
b_{r1}				1		
f_{s2}					1	
f_{r2}			1			
b_{s2}						1
b_{r2}				$-\epsilon^{-j/3(\theta_3-\theta_1)}$		

(18)

The various tensors of the individual selsyns are given in reference 10. The resultant transient Z tensor of the interconnected system is found by

$$Z'=C_i{}^{*}\cdot Z\cdot C+C_i{}^{*}pL\cdot C \quad (19)$$

given in equation 21. The corresponding equivalent circuits are shown in Figure 2. The voltages ΔE impressed on the hunting networks are given in equation 22. The torques are found by

$$\Delta T=i\cdot\Delta E^{*}+\Delta i\cdot E^{*}+i^{*}\cdot\frac{\partial G}{\partial\delta}\cdot i\,\Delta\delta \quad (20)$$

$Z=\frac{1}{4}\times$

	f_1	b_1	f_r	b_r	f_2	b_2
f_1	$r_{sd1}+r_{sq1}+(L_{sd1}+L_{sq1})p$	$r_{sd1}-r_{sq1}+(L_{sd1}-L_{sq1})p$	$(M_{d1}+M_{q1})p$	$(M_{d1}-M_{q1})p$		
b_1	$r_{sd1}-r_{sq1}+(L_{sd1}-L_{sq1})p$	$r_{sd1}+r_{sq1}+(L_{sd1}+L_{sq1})p$	$(M_{d1}-M_{q1})p$	$(M_{d1}+M_{q1})p$		
f_r	$(M_{d1}+M_{q1})(p-jp\theta_1)$	$(M_{d1}-M_{q1})(p-jp\theta_1)$	$2r_{r1}+(L_{rd1}+L_{rq1})\cdot(p-jp\theta_1)+2r_{r1}+(L_{rd2}+L_{rq2})\cdot(p-jp\theta_1)$	$(L_{rd1}-L_{rq1})(p-jp\theta_1)+(L_{rd2}-L_{rq2})\epsilon^{-3j\delta}[p-j(2p\theta_2-p\theta_1)]$	$-(M_{d2}+M_{q2})\cdot(p-jp\theta_1)$	$-(M_{d2}+M_{q2})\cdot(p-jp\theta_1)$
b_r	$(M_{d1}-M_{q1})(p+jp\theta_1)$	$(M_{d1}+M_{q1})(p+jp\theta_1)$	$(L_{rd1}-L_{rq1})\cdot(p+jp\theta_1)+\epsilon^{3j\delta}(L_{rd2}-L_{rq2})\cdot[p+j(2p\theta_2-p\theta_1)]$	$2r_{r1}+(L_{rd1}+L_{rq1})\cdot(p+jp\theta_1)+2r_{r2}+(L_{rd2}+L_{rq2})\cdot(p+jp\theta_1)$	$-\epsilon^{3j\delta}(M_{d2}-M_{q2})[p+j(2p\theta_2-p\theta_1)]$	$-\epsilon^{3j\delta}(M_{d2}+M_{q2})\cdot[p+j(2p\theta_2-p\theta_1)]$
f_2			$-(M_{d2}+M_{q2})\cdot[p+j(p\theta_2-p\theta_1)]$	$-(M_{d2}-M_{q2})\cdot\epsilon^{-3j\delta}[p-j(p\theta_2-p\theta_1)]$	$r_{sd2}+r_{sq2}+(L_{sd2}+L_{sq2})\cdot[p+j(p\theta_2-p\theta_1)]$	$r_{sd2}-r_{sq2}+(L_{sd2}-L_{sq2})\cdot[p+j(p\theta_2-p\theta_1)]$
b_2			$-(M_{d2}-M_{q2})\cdot[p+j(p\theta_2-p\theta_1)]$	$-(M_{d2}+M_{q2})\epsilon^{-3j\delta}\cdot[p-j(p\theta_2-p\theta_1)]$	$r_{sd2}-r_{sq2}+(L_{sd2}-L_{sq2})[p+j(p\theta_2-p\theta_1)]$	$r_{sd2}+r_{sq2}+(L_{sd2}+L_{sq2})\cdot[p+j(p\theta_2-p\theta_1)]$

(21)

$$\Delta E = \frac{1}{4} \times$$

	$\Delta\theta_2$	$\Delta\theta_1$
f_1		
b_1		
f_r	$(L_{rd2}-L_{rq2})\epsilon^{-2j\delta}\{-2ji^{2r}p-2j[p-j(2p\theta_2-p\theta_1)]i^{2r}\}$	$4E_{f1}p-j[(X_{rd2}+X_{rq2})i^{fr}-(X_{md2}+X_{mq2})i^{2s}]p+(L_{rd2}-L_{rq2})\epsilon^{-2j\delta}\{ji^{2r}p+2j[p-j(2p\theta_2-p\theta_1)]i^{2r}\}$
b_r	$(L_{rd2}-L_{rq2})\epsilon^{2j\delta}\{2ji^{fr}p+2j[p+j(2p\theta_2-p\theta_1)]i^{fr}\}+(M_{d2}-M_{q2})\epsilon^{2j\delta}\{-2ji^{fs}p-2j[p+j(2p\theta_2-p\theta_1)]i^{fs}\}+(M_{d2}+M_{q2})\epsilon^{2j\delta}\{-2ji^{2s}p-2j[p+j(2p\theta_2-p\theta_1)]i^{2s}\}$	$4E_{b1}p+j(X_{rd2}+X_{rq2})i^{2r}p+(L_{rd2}-L_{rq2})\epsilon^{2j\delta}\{-ji^{fr}p-2j[p+j(2p\theta_2-p\theta_1)]i^{fr}\}+(M_{d2}-M_{q2})\epsilon^{2j\delta}\{ji^{fs}p+2j[p+j(2p\theta_2-p\theta_1)]i^{fs}\}+(M_{d2}+M_{q2})\epsilon^{2j\delta}\{ji^{2s}p+2j[p+j(2p\theta_2-p\theta_1)]i^{2s}\}$
f_2	$(M_{d2}-M_{q2})\epsilon^{-2j\delta}\{ji^{2r}p+2j[p-j(p\theta_2-p\theta_1)]i^{2r}\}+4je_{f1}\epsilon^{-j\delta}-j[(X_{md2}+X_{mq2})i^{fr}-(X_{sd2}+X_{sq2})i^{fr}-(X_{sd2}-X_{sq2})i^{2s}]p$	$(M_{d2}-M_{q2})\epsilon^{-2j\delta}\{-ji^{2r}p-2j[p-j(p\theta_2-p\theta_1)]i^{2r}\}-4je_{f1}\epsilon^{-j\delta}+j[(X_{md2}+X_{mq2})i^{fr}-(X_{sd2}+X_{sq2})i^{fr}-(X_{sd2}-X_{sq2})i^{2s}]p$
b_2	$(M_{d2}+M_{q2})\epsilon^{-2j\delta}\{ji^{2r}p+2j[p-j(p\theta_2-p\theta_1)]i^{2r}\}+4je_{b1}\epsilon^{-j\delta}-j[(X_{md2}-X_{mq2})i^{fr}-(X_{sd2}-X_{sq2})i^{fr}-(X_{sd2}+X_{sq2})i^{2s}]p$	$(M_{d2}+M_{q2})\epsilon^{-2j\delta}\{-ji^{2r}p-2j[p-j(p\theta_2-p\theta_1)]i^{2r}\}-4je_{b1}\epsilon^{-j\delta}+j[(X_{md2}-X_{mq2})i^{fr}-(X_{sd2}-X_{sq2})i^{2}-(X_{sd2}+X_{sq2})i^{2s}]p$

(22)

It should be noted that no matter how the expressions in ΔE are grouped, they cannot be measured on the steady-state network. However if the following matrix (equation 14) is added to ΔE

$$\frac{1}{4} \times$$

	$\Delta\theta_2$	$\Delta\theta_1$
f_1		
b_1		
f_r	$(L_{rd2}-L_{rq2})(p-jp\theta_2)\epsilon^{-2j\delta}2ji^{2r}-(L_{rd2}-L_{rq2})(p-jp\theta_2)\epsilon^{-2j\delta}2ji^{2r}$	$-(L_{rd2}-L_{rq2})(p-jp\theta_2)\epsilon^{-2j\delta}2ji^{2r}+(L_{rd2}-L_{rq2})(p-jp\theta_2)\epsilon^{-2j\delta}2ji^{2r}$
b_r	$(L_{rd2}+L_{rq2})(p+jp\theta_2)2ji^{2r}-(L_{rd2}+L_{rq2})(p+jp\theta_2)2ji^{2r}$	$-(L_{rd2}+L_{rq2})(p+jp\theta_2)2ji^{2r}+(L_{rd2}+L_{rq2})(p+jp\theta_2)2ji^{2r}$
f_2	$-(M_{d2}-M_{q2})\epsilon^{-2j\delta}2jpi^{2r}+(M_{d2}-M_{q2})\epsilon^{-2j\delta}2jpi^{2r}$	$(M_{d2}-M_{q2})\epsilon^{-2j\delta}2jpi^{2r}-(M_{d2}-M_{q2})\epsilon^{-2j\delta}2jpi^{2r}$
b_2	$-(M_{d2}+M_{q2})\epsilon^{-2j\delta}2jpi^{2r}+(M_{d2}+M_{q2})\epsilon^{-2j\delta}2jpi^{2r}$	$(M_{d2}+M_{q2})\epsilon^{-2j\delta}2jpi^{2r}-(M_{d2}+M_{q2})\epsilon^{-2j\delta}2jpi^{2r}$

(23)

then in the presence of these additional expressions the components of ΔE may be regrouped and expressed in terms of measurable voltages and currents as

$$\Delta E = \frac{1}{4} \times$$

	$\Delta\theta_2$	$\Delta\theta_1$
f_1		
b_1		
f_r	$-2j(X_{md2}-X_{mq2})\epsilon^{-2j\delta}(1+h-v)ji^{2r}$	$2j(X_{md2}-X_{mq2})\epsilon^{-2j\delta}(1+h-v)ji^{2r}+4j(E_{f1}+E_{f2})h$
b_r	$-j(X_{rd2}+X_{rq2})2ji^{2r}(1+h+v)+8jE_{b2}(1+h+v)$	$j(X_{rd2}+X_{rq2})2ji^{2r}(1+h+v)-8jE_{b2}(1+h+v)+4j(E_{b1}+E_{b2})h$
f_2	$2j(X_{md2}-X_{mq2})\epsilon^{-2j\delta}(1+h)ji^{2r}-4jE_{f1}h+4jE_{f1}\epsilon^{-j\delta}$	$-2j(X_{md2}-X_{mq2})\epsilon^{-2j\delta}(1+h)ji^{2r}+4jE_{f1}h-4je_{f1}\epsilon^{-j\delta}$
b_2	$2j(X_{md2}+X_{mq2})\epsilon^{-2j\delta}(1+h)ji^{2r}+4jE_{b1}h+4je_{b1}\epsilon^{-j\delta}$	$-2j(X_{md2}+X_{mq2})\epsilon^{-2j\delta}(1+h)ji^{2r}-4jE_{b2}h-4je_{b1}\epsilon^{-j\delta}$

(24)

Similarly, it should be noted that in the torque equation 20 the last term cannot be measured off the hunting network. Hence, if to the torque equation the following matrix (equation 17)

$$-\eta_i^{\circ}\cdot V\cdot i+\eta_i^{\circ}\cdot V\cdot i=$$

	$\Delta\theta_2$	$\Delta\theta_1$
f_r	$-j(X_{rd2}-X_{rq2})\epsilon^{-2j\delta}2ji^{2r}+j(X_{rd2}-X_{rq2})\epsilon^{-2j\delta}2ji^{2r}$	$j(X_{rd2}-X_{rq2})\epsilon^{-2j\delta}2ji^{2r}-j(X_{rd2}-X_{rq2})\epsilon^{-2j\delta}2ji^{2r}$
b_r	$j(X_{rd2}+X_{rq2})2ji^{2r}-j(X_{rd2}+X_{rq2})2ji^{2r}$	$-j(X_{rd2}+X_{rq2})2ji^{2r}+j(X_{rd2}+X_{rq2})2ji^{2r}$

(25)

is added, then the torque equation may be regrouped, expressed as

$$\Delta T = i\cdot\Delta E'^{\circ}+\Delta i\cdot E^{\circ} \qquad (26)$$

and measured off the hunting network as usual.

The corresponding equivalent circuits are given in Figure 2 and the torque measurements in Table I. There are two similar hunting networks for each case of hunting, one containing everywhere $+h$ the other $-h$.

The two shaded circles represent a phase shifter, one shifting the current, the other the voltage by an angle 2δ. In writing equations for the armature mesh b_r by tracing out the equivalent circuit, it has to be remembered that only one equation need be written since the current generators form only junction pairs.

It should be noted that the curvature tensor enters only in the establishment of the voltage generator $2jE_b$ and the current generator $2ji^b$ that appear at the terminals of the machines.

Synchronous Machines

The same method of reasoning applies when two salient-pole synchronous machines are interconnected. Their equivalent circuits are given in Figure 3 and the torque measurements in Table II.

When a synchronous machine is connected to a transmission line, two cases are possible:

1. The reference frame is rigidly connected to the field pole, and the frame takes part in the oscillation. This case was considered in reference 11. The disadvantage of the resulting equivalent circuit of hunting is that it requires as many generators as there are meshes in the transmission line.

2. The reference frame is rigidly connected to the infinite bus. Since the latter is not assumed to hunt, the transmission network is free of generators. They appear now in the synchronous-machine field meshes, whose number is however few. The equivalent circuits for this case are given in Figure 4 and the torque measurements in Table III. The two Figures 5 and 6 are reproduced from reference 11.

The results of a study made on Figures 4–6 are given in a companion paper.[12]

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Abnormal Overvoltages Caused by Transformer Magnetizing Currents in Long Transmission Lines

H. A. PETERSON
MEMBER AIEE

T. W. SCHROEDER
ASSOCIATE AIEE

As power-transmission distances have increased, new problems, both technical and economic have been encountered, analyzed, and taken into consideration in the design and operation of power systems. As transmission distances continue to increase it is logical to expect that in addition to the already exposed problems, new ones may arise which previously have not required consideration. It is the purpose of this paper to present an analysis of a technical problem which falls in the latter category.

In the course of studying various problems associated with long-transmission-line phenomena, it has been found by means of the transient analyzer that certain combinations of transmission-line length and system reactance can give rise to overvoltages of considerable magnitude when a lightly loaded transformer is connected to that transmission line. It is shown in the paper that such a system is most susceptible to overvoltage phenomena when the transformer is connected to the receiving end of that transmission line, although, theoretically, similar phenomena may occur for any transformer location including the transformer at the sending end. These overvoltages are in addition to the normal fundamental-frequency voltage rise and are of a combination subharmonic and harmonic nature. In magnitude, this overvoltage may be twice as high as that which can be calculated by conventional methods when transformer magnetizing currents are neglected.

A comprehensive analysis of representative circuits with and without series-capacitor compensation has been made to determine the regions of abnormal behavior and the effectiveness of various practical methods for safely limiting such overvoltages. Such practical means for controlling the overvoltage include proper switching and relaying arrangements, the synchronous condenser, shunt reactors, and resonant shunts.

The results presented include a physical picture of the underlying mechanism which gives rise to the phenomenon. It is felt that these results will be of considerable importance from the standpoint of designing and operating systems involving the transmission of power over distances in the practical range above 200 miles.

Paper 43-7, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted October 9, 1942; made available for printing November 2, 1942.

H. A. PETERSON and T. W. SCHROEDER are both with central station engineering department, General Electric Company, Schenectady, N. Y.

The authors acknowledge the helpful suggestions of S. B. Crary and the assistance of J. E. Paul, H. C. Anderson, and R. C. Prim in obtaining and summarizing the data presented in this paper.

Summary and Conclusions

The phenomena discussed in this paper are more likely to occur when the transformer is located at the receiving end and is lightly loaded or carrying no load. While an unloaded or lightly loaded transformer located at any point along a transmission line can give rise to these overvoltage phenomena, the system is most susceptible to such disturbances when the transformer is at the receiving end of the line because of the normal frequency rise in voltage with increasing distance from the source end. It should be borne in mind that either end of a long transmission line may become the receiving end in the sense employed in this study. The condition would probably be most serious when accompanied by generator overspeeding immediately following sudden loss of load caused by low side switching, which would simultaneously remove any receiving-end synchronous-condenser capacity otherwise normally present.

In designing a power system requiring transmission distances in the practical range above 200 miles, consideration should be given to the possibility of overvoltages such as these discussed in the paper. The more important factors the effects of which should be evaluated are

1. System frequency (including range due to generator overspeeding).
2. System reactance.
3. Line length and losses.
4. Receiving-end transformer size and saturation characteristics.
5. Switching arrangement

(a). Use of high side breakers, with proper relaying, may prevent unloaded transformers from every being on the receiving end of the line.

(b). If no high side breakers are used, care should be taken so that the receiving-end synchronous-condenser capacity is operated as an integral part of the line and receiving-end transformer.

6. Series capacitors.

Remedial measures which are effective in eliminating the overvoltages for cases falling in the danger region include the following:

1. Switching arrangements (see 5 above).
2. Synchronous condensers.
3. Shunt reactors.
4. Second harmonic shunts.

Shunt reactors or the second harmonic shunt should be an integral part of the line, preferably located at or near the terminals of the receiving-end transformer for maximum effectiveness. They need not be on the high-voltage side of the transformer. To make the second harmonic shunt effective over a range of frequencies likely to be encountered as a result of possible overspeeding, it would be preferable to have it tuned for a frequency slightly higher than the second harmonic. However, with series capacitors, the second harmonic shunt alone is not capable of stabilizing the voltage at the receiver end.

In some specific cases it may be desirable to set up the system in miniature to

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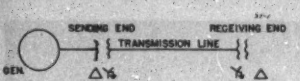


Figure 1. One-line diagram of system studied

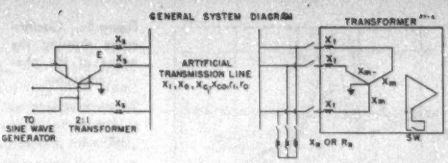


Figure 2. Three-phase miniature system equivalent of the system shown in Figure 1

evaluate accurately the effects of all of the factors involved under various conditions of operation.

System Studied

Figure 1 shows the basic circuit analyzed. In a system such as this, the receiving-end transformer would become considerably overexcited if its load were suddenly lost during a system disturbance severe enough to cause the receiving-end low-voltage circuit breakers to open. This would leave the transformer energized with no load and thus with only exciting current flowing. However, the magnetizing impedance of a transformer, while fundamentally reactive, is a variable quantity because of saturation of the iron core. During periods of saturation, relatively high peak currents may flow momentarily.

Analysis of the problem involving a distributed constant line, and a saturable reactance would be extremely complicated and time-consuming using ordinary methods. Therefore the transient-analyzer method of miniature-system representation, which is ideally suited to the study of such nonlinear circuit phenomena,[9,10,11] was used. For the purpose of analysis by this method, the system of Figure 1 was set up as shown in Figure 2. The artificial transmission line and the miniature transformers used at the receiving end have been described previously,[1,2] and so no space will be devoted to a description of the miniature system in this paper. It will be sufficient to point out that the abruptness of transformer saturation could be varied simply by varying X_t as shown in Figure 3. The values of X_t used were always small relative to X_m so that X_m remained substantially independent of X_t/X_m. Consequently the connected receiving transformer kilovolt-amperes remained essentially independent of X_t/X_m, and only the saturation characteristic of the receiving-end transformer was modified by varying X_t/X_m as shown in Figure 3. Each single-phase transformer used at the receiving end had a magnetizing impedance of X_m=13,000 ohms at normal voltage of 110 volts. Two of these units could be put in each phase in parallel, thus halving the value of X_m, or two units could be put in series in each phase (provided values of *E in volts* were doubled) thus doubling the value of X_m. In any case, the receiving-end transformer kilovolt-amperes to be associated with any value of X_m is given by the following relation.

$$X_m = \frac{\text{kv}^2 \times 1{,}000}{\text{kva} \times I_m}$$

where

X_m is the receiving-end transformer magnetizing reactance in ohms per phase at normal voltage
Kv is normal system line-to-line voltage
Kva is the receiving-end transformer-bank rating
I_m is the exciting current in per unit per phase at normal voltage.

Thus, if X_m=13,000 ohms, and if a three per cent exciting current and a 230-kv system are assumed, the receiver-end transformer kilovolt-ampere rating represented by the miniature system would be

$$\text{kva} = \frac{(230)^2(1{,}000)}{13{,}000(0.03)} = 135{,}000 \text{ kva}$$

Provision was made for operating the receiving-end transformer with or without the delta open. Shunt reactors or resistors of variable kilovolt-ampere rating, as well as resonant shunts and synchronous condensers, could be switched in at the receiving end. Series capacitors for line-reactance compensation could be inserted as desired. Provision was made for varying the resistance of the transmission line and of the receiving-end transformer and for varying the sine-wave generator voltage, thus changing the operating flux density in the receiving-end transformer as desired. Consequently numerous factors separately or in combination could be carefully studied.

The effect of lightning arresters in limiting these overvoltages and thus protecting terminal equipment was not included in this study. It follows from the results revealing the nature of the phenomenon, however, that lightning arresters may be damaged by such sustained overvoltages.

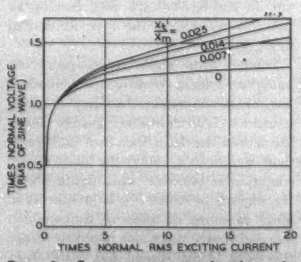


Figure 3. Saturation curves used in this study

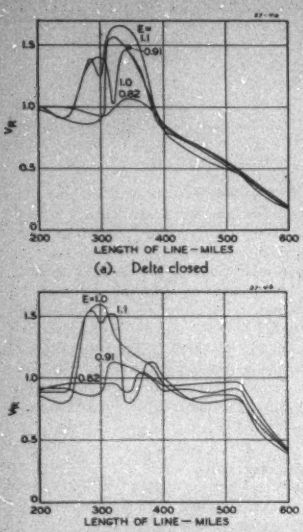
D-c resistance of winding expressed as a ratio to X_m is 0.0003. X_m=13,000 ohms at 110 volts, 60 cycles, for one transformer

Nomenclature

E = voltage back of X_s in per unit
X_s = source reactance
X_t = transformer series reactance (for saturation adjustment)
x_0/x_1 = zero-sequence line reactance / positive-sequence line reactance
r_1/x_1 = line resistance / line reactance (positive sequence)
V_R = voltage at receiving end with transformer / voltage at receiving end without transformer
X_{c1}/X_R = (positive-sequence capacitive reactance) / shunt reactance
r_0/x_0 = line resistance / line reactance (zero sequence)
f = cycles per second
X_m = magnetizing reactance in ohms at normal voltage and frequency
X_{c1}, X_{c0} = positive- and zero-sequence shunt capacitive reactance of line respectively
X_{sc} = series-capacitor reactance
X_L = nonsaturable reactance in parallel with X_{sc}
R = resistance in parallel with X_{sc}
X_R = nonsaturable shunt reactance at receiving-end transformer terminals
R_R = shunt resistors at receiving-end transformer terminals

Discussion of Results

With the system set up as in Figure 2, curves as shown in Figures 4a and 4b were obtained. It should be emphasized that the voltage V_R is a ratio of crest voltage to ground at the receiver end with the transformer connected, to the crest voltage at the same location with the transformer disconnected. Thus the normal rise in the line is eliminated from



(a). Delta closed

(b). Delta open

Figure 4. Voltages V_R obtained in the system of Figure 2

$X_s = 86$ ohms
$f = 60$ cycles per second
$x_0/x_1 = 4.0$
$r_1/x_1 = 0.1$
$X_t/X_m = 0.014$
$X_m = 13{,}000$ ohms
No series-capacitor compensation
No load on system
No shunt reactors

the results, and the effect of the transformer alone is shown by these figures.

The oscillograms shown in Figure 5 are typical illustrations. No two of these oscillograms were taken simultaneously, so it is not possible to correlate instantaneous values of voltage and current. However, the variation in voltage and current wave shapes with time is indicated. The voltage is seen to be made up largely of a second harmonic and subharmonics. The current traces clearly show evidence of subharmonics and even harmonics. The time required for this condition to be reached following sudden loss of load varies from a couple of cycles to a second or two depending upon the value of E and the system constants.

The values of E maintained back of X_s range from a maximum of 1.1 down to values such that the effect of the transformer is negligible from the standpoint of producing overvoltages. It is felt that this covers the practical range, including the case of sudden loss of load at the receiving end. Unit voltage $E = 1.0$

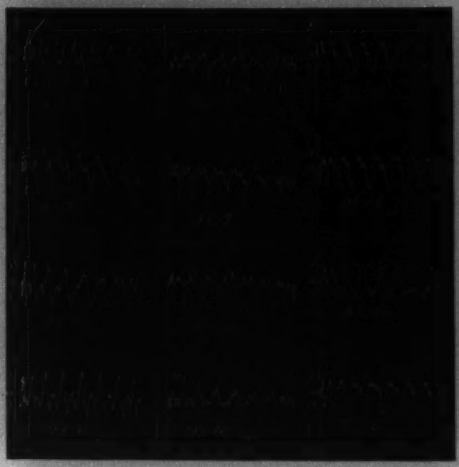
Figure 5. Oscillograms showing the nature of the phenomenon

System constants as in Figure 4a, with 320 miles of line

A. V_R—Phase-A voltage to ground at receiving-end transformer terminals

B. Receiving-end phase-A transformer magnetizing current

C. Voltage to ground at sending end times that which would exist without the transformer



defines the normal operating point on the saturation curves of Figure 3 when applied directly to the terminals of the transformer.

It is to be noted that if E is reduced approximately to values such that the receiving-end transformer is not overexcited, no overvoltages will occur. It is of significance also that the region of abnormality is not greatly affected by the delta being opened or closed. Furthermore, the phenomenon is essentially independent of the method of grounding the receiving-end transformer neutral when a closed delta winding is present.

It should be noted that, while the system studied is characterized by a "sending end" and a "receiving end," in the actual case, either end may become the receiving end in the sense employed here. That is, during a system disturbance, either end of the line may be switched out on the low-voltage side, leaving an unloaded system of the type illustrated in Figure 2.

Similar tests made under numerous miniature-system conditions have made it possible to summarize the effect of source reactance X_s as shown in Figure 6. Since the case of the delta open is of little practical significance, only the delta-closed condition is shown. This figure shows the regions in which V_R is greater than unity in terms of miles of transmission line and source reactance in ohms. Since the delta being opened has little effect on the region of abnormality in general, it is to be concluded that the reactance of the tertiary winding is of little consequence. Furthermore the negligible effect of the delta being opened has some significance from the standpoint of the theory involved, as will be shown later.

The curves of Figure 6 indicate that overvoltages are to be expected over a range of line lengths from 200 miles on up to slightly over 400 miles when the system frequency is 60 cycles per second, and source reactances are in the practical range. With lower frequencies the line lengths could be increased inversely as the frequency before encountering the difficulty. The maximum value of V_R obtained was 1.8 with the delta closed, and the length of line producing the maximum overvoltage is shown to increase as the source reactance decreases. Thus, under system conditions corresponding to these, voltages on the order of twice those normally expected may exist at the terminals of the receiving-end transformer if the line length and system source reactance are in the right combination, and if corona and lightning arresters are not voltage-limiting factors.

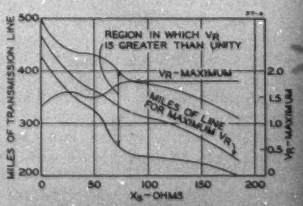


Figure 6. Boundaries of overvoltage region as affected by line length and source reactance with receiving-end transformer delta closed

Frequency 60 cycles per second

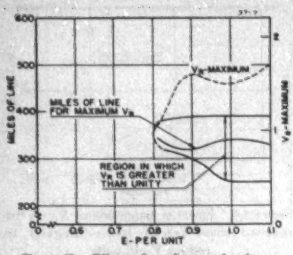


Figure 7. Effect of sending-end voltage

System constants as in Figure 4a

While the curves of Figure 6 are for the transformer located at the receiving end of the transmission line, it can be shown (see Appendix II) that the critical combination of length of line and source reactance which is susceptible to these phenomena is independent of the transformer location. Even the sending-end transformer can produce the same phenomena for the same range of constants shown in Figure 6. However, a somewhat higher range of values of E (voltage back of equivalent system reactance, X_s) would be required to give rise to the phenomenon in this case. The receiving-end transformer location renders a given system more vulnerable to such disturbances because of the normal-frequency voltage rise in the line.

The effect of the voltage E maintained within the system is shown in Figure 7 for the same case as in Figure 4. As the system voltage is decreased, the range of system constants capable of giving rise to this abnormality decreases, and at $E=0.8$ the phenomenon disappears entirely. This suggests the theoretical possibility of avoiding such overvoltage phenomena by using low-flux density transformers, although other means may generally be more desirable.

The effect of varying the magnetizing reactance X_m is illustrated in Figure 8. It is believed that this covers the practical

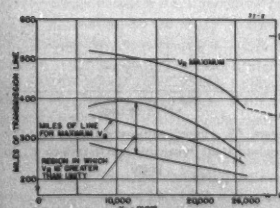

MILES OF TRANSMISSION LINE
V_R MAXIMUM
MILES OF LINE FOR MAXIMUM V_R
REGION IN WHICH V_R IS GREATER THAN UNITY
V_R - MAXIMUM
X_m - OHMS

Figure 8. Effect of varying the receiving-end transformer magnetizing reactance X_m

System constants as in Figure 4a

range of X_m and shows that the phenomenon is not critical to a particular value of X_m. Obviously if X_m is ∞ the value of $V_R=1$ as shown, and if very high values of X_m are connected to the transmission line, little disturbance of the type under discussion would be expected. In order to make the results more general, values of X_m are given in ohms, but they can readily be converted to specific transformer kilovolt-ampere ratings in systems of given voltage rating, if the magnetizing current in per cent is known or assumed. The formula given in the preceding section can be used for this purpose.

The effect of line resistance is illustrated in Figure 9. It appears that, if r_1/x_1 could be as high as 0.4 or higher, the phenomena would not occur. However, practical values of r_1/x_1 in lines such as these under discussion would fall considerably below this value—on the order of 0.2 or less. Therefore line resistance would not be expected to eliminate the overvoltages in a practical case. Furthermore, any attempt to increase the circuit resistance may result in an increased tendency for hunting to take place.[3,4,13]

The effect of steepness of saturation is illustrated in Figure 10. It is evident from this illustration that the phenomenon is not critical to the abruptness of saturation over a practical range, although the more abrupt saturation characteristic in general appears to lead to higher voltages and broaden the range of constants for which they may be obtained.

The effect of generator overspeeding is illustrated in Figure 11. A system normally not in the region of overvoltages may be brought into the region by generator overspeeding as a result of loss of load.

After observing the effects of various factors in producing these overvoltages, means were investigated for controlling them. Among the first means investigated was shunt reactors placed at the terminals of the receiving-end transformer. The ability of reactors to accomplish the desired purpose is illustrated in Figure 12. It is interesting to note that shunt reactor kilovolt-amperes as high as 65 per cent of normal line-charging kilovolt-amperes may be required to keep V_R down to unity. This amount of reactance does not include compensation for the normal rise in the line since V_R as defined is independent of the normal rise in voltage in the line. If generator overspeeding is an appreciable factor, shunt reactors to take care of the normal fundamental-frequency rise in the line may not prevent the occurrence of this phenomenon because of the increase in applied frequency.

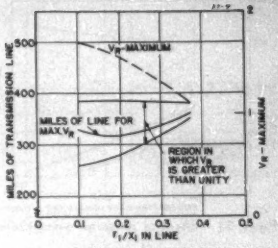

MILES OF TRANSMISSION LINE
V_R-MAXIMUM
MILES OF LINE FOR MAX V_R
REGION IN WHICH V_R IS GREATER THAN UNITY
V_R - MAXIMUM
r_1/x_1 IN LINE

Figure 9. Effect of line resistance

System constants as in Figure 4a

Figure 13 indicates that if the receiving-end transformer saturates more abruptly, more reactor kilovolt-amperes may be required to stabilize the voltages

Figure 14 suggests that the maximum required X_c/X_R is likely to increase as the value of X_m decreases. This is representative for the practical range of X_m.

Figure 15 shows that a synchronous condenser is very effective in eliminating the overvoltage hazard. In most actual cases, a condenser at the receiver end of a size greater than the minimum required for overvoltage stability would likely be present. Consequently this is one very practical and effective means of overcoming the difficulty. However, provision must be made for keeping the condenser on the system, even though the load is lost. Thus, in addition to controlling the fundamental-frequency voltage at the receiver end during normal load conditions, a condenser is expected to be effective in eliminating abnormal harmonic and subharmonic voltages such as these during system disturbances.

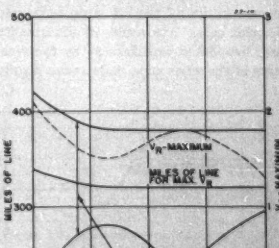


Figure 10. Effect of abruptness of transformer saturation at receiving end

System constants as in Figure 4a

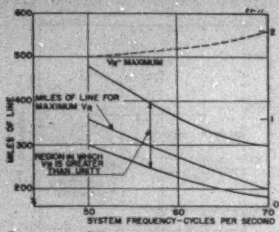

MILES OF LINE
MILES OF LINE FOR MAXIMUM V_R
V_R MAXIMUM
V_R - MAXIMUM
REGION IN WHICH V_R IS GREATER THAN UNITY
SYSTEM FREQUENCY—CYCLES PER SECOND

Figure 11. Effect of generator overspeeding

System constants as in Figure 4a

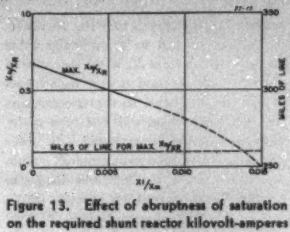


Figure 13. Effect of abruptness of saturation on the required shunt reactor kilovolt-amperes to reduce V_R to unity

System constants as in Figure 4a

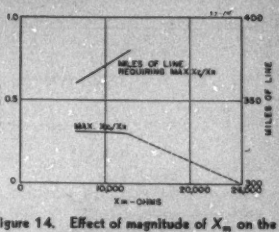


Figure 14. Effect of magnitude of X_m on the required shunt reactor kilovolt-amperes to reduce V_R to unity

System constants as in Figure 4a

The curves of Figure 15 require some discussion, because they show a minimum condenser requirement for the length of line giving rise to the maximum values of V_R. Practically, however, the necessity for reducing V_R at all is greatest when V_R is greatest. Therefore, for practical purposes, the maximum condenser requirements for this given case are more nearly the minimum values shown in Figure 15. In other words, a condenser of 15,000 kva would probably be adequate for keeping V_R from becoming destructive in magnitude for this case.

One other very effective means that has been found for eliminating the overvoltages is the resonant shunt located at the receiver-end transformer. The shunt may be either delta- or wye-connected. If wye-connected, it makes no difference whether the neutral point is grounded or not. Its effectiveness is illustrated in Figure 16. The reason for the effectiveness of the second harmonic shunt is discussed in the following section.

The effect of series capacitors at the mid-point of the transmission line is illustrated in Figure 17. Series capacitors at the mid-point of the line for 50 per cent compensation of the line drop were used for this case. The region of abnormality was broadened considerably by the presence of the series capacitors as can readily be seen by comparing this figure with Figure 4a or 4b. The reason for this broadening of the region of abnormality is that an additional phenomenon, different in nature, is introduced by the presence of series capacitors.[4] This is discussed further in the section headed "Theory."

It is possible to eliminate the phenomenon entirely by using shunt reactors located at the terminals of the receiving-end transformer. The amount of reactance required is shown for one case in Figure 18. In this figure also is shown the amount of shunt resistance required for the same case.

The possibility of using a resistor in shunt with the series capacitor has previously been given some consideration.[4] A reactor in parallel with the series capacitor also is effective as shown in Figure 19, although for this case, the effectiveness of either a resistor or reactor so placed decreases rapidly for lengths of line above 280 miles.

In Figure 20, the curves show the amount of reactance or resistance required in parallel with the series capacitor for the same case, the only difference being that a second-harmonic resonant shunt has been connected to the terminals of the receiving-end transformer. Reactance is seen to be quite effective as a means of eliminating the phenomenon in this case for line lengths up to well over 400 miles, while resistance is not nearly so effective. Furthermore, resistance is undesirable since it introduces losses during normal load conditions which in the proportions required would be intolerable in some cases.

A condenser of practical size at the receiving end is very effective in eliminating the voltage instability, either with or without series capacitors.

Theory

The cause of the phenomena discussed in the preceding section can best be understood by first considering a single-phase circuit as shown in Figure 21. Here the essential elements of the three-phase circuit of Figure 2 are present, the transmission line being represented by a capacitor, X_c, and the source reactance by X_L. The transformer X_m which can be connected or disconnected by the switch, corresponds to the receiving-end transformer of Figure 2 where X_t and X_m define the transformer characteristics.

With V_R defined as in the preceding discussion the results obtained by varying X_c/X_L and X_m/X_L are shown in Figure 22. Here two peaks of overvoltage are

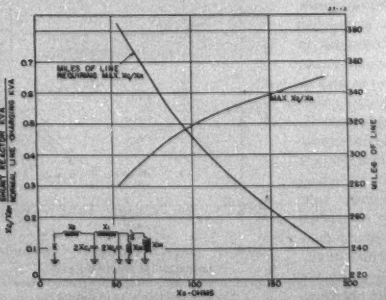


Figure 12. Maximum shunt reactance kilovolt-amperes at receiving-end transformer terminals required to reduce V_R to unity

Shunt-reactor kilovolt-amperes expressed as a ratio to normal line-charging kilovolt-amperes in accordance with the insert. System constants as in Figure 4a

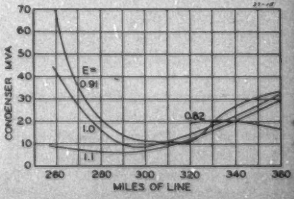


Figure 15. Synchronous-condenser capacity required at the receiving end to reduce V_R to unity

System as in Figure 4a, with $X_l/X_m = 0$, transient reactance of condenser assumed to be 30 per cent on rating in 230-kv system. Voltage back of transient reactance of condenser, 133 per cent

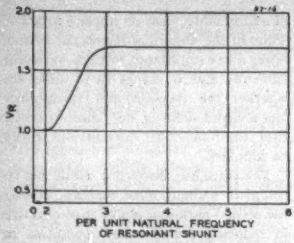


Figure 16. Effect of resonant shunt on V_R

Shunt consists of reactor and capacitor in series located at the terminals of the receiving-end transformer. Reactor 6.0 henrys. Capacitance varied. System constants as in Figure 4a with 320 miles of line

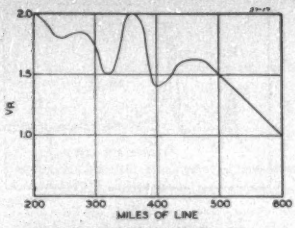


Figure 17. Relationship between V_R and miles of line with series capacitors

Series-capacitor kilovolt-amperes at mid-point of line correcting for 50 per cent of line reactance drop. System constants as in Figure 4a. $E \leq 1.1$

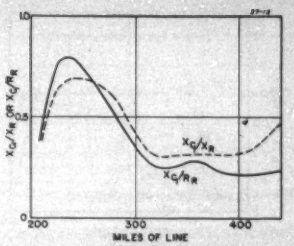


Figure 18. Shunt reactance or resistance required at the receiving-end transformer terminals to hold V_R down to unity for $E \leq 1.1$

System constants as in Figure 4a with 50 per cent series-capacitor line-reactance drop compensation at the mid-point of the line

shown, one largely of second-harmonic and subharmonic nature for X_c/X_L just below 4 and the other largely of third-harmonic nature for X_c/X_L just below 9. The higher values of X_m/X_L cause the peaks of overvoltage to move closer to 4 and 9 respectively. Now when $X_c/X_L = 4$, the circuit viewed from the switch location with the switch open is tuned to the second harmonic, and when $X_c/X_L = 9$, it is tuned to the third harmonic.

For the case of X_c/X_L just below 9, it is not difficult to see why overvoltages will occur. If $X_c/X_L = 9$, the impedance of the circuit viewed from the switch with the switch open is infinite to the third harmonic neglecting resistance. Consequently, in trying to supply the required third to the transformer, a large third-harmonic drop is encountered, and this shows up at the transformer terminals as indicated in the curves. If X_c/X_L is lower than about 7.5 and higher than about 12, the impedance to the third harmonic required by the transformer is low enough essentially to eliminate the overvoltages of the third-harmonic type.

It is to be noted that the overvoltages of this type are a maximum when X_c/X_L is slightly less than 9. This means that the system impedance is capacitive and o a high value to the third harmonic. This is to be expected since, with the switch closed, the path for third harmonics includes X_m also, which, while difficult to evaluate under these saturated conditions, nevertheless is fundamentally reactive to the third and probably compensates for the resultant capacitive reactance of the system to bring the overall system more nearly in tune to the third harmonic at the point giving rise to the maximum V_R shown in Figure 22.

With regard to the peak values of V_R for X_c/X_L slightly less than 4, the explanation is more difficult, because, while the system impedance with the switch open is infinite (neglecting resistance) to the second harmonic when $X_c/X_L = 4$, the transformer in normal steady-state operation with sinusoidal voltage applied does not require a second harmonic to flow. Consequently the preceding explanation, while satisfactory for the region of third-harmonic overvoltages is not satisfactory for the region of second-harmonic overvoltages.

In order to visualize the cause of the second-harmonic overvoltages, it is desirable to substitute the equivalent circuit of Figure 23 for the circuit of Figure 21. In this figure, the two reactances X_L and X_c correspond to the reactances so labelled in Figure 21. The reactances X_m and X_r are constant (not saturable) and represent the transformer of Figure 21.

In this equivalent circuit, the saturation of the transformer is represented by two straight lines as shown in Figure 23b. The effect of saturation of this type is introduced in the equivalent circuit by closing switch S at every instant that the current i into the equivalent transformer exceeds a critical value and opening it at every instant that the current i falls below this critical value. In the illustration of Figure 23b, this critical value has been arbitrarily taken to be 0.9 of the crest value which would be taken by X_m if the switch S were never closed. On this basis the switch S would be opened and closed every half-cycle of fundamental frequency, or the switching cycle would be repeated at a frequency corresponding essentially to second-harmonic frequency, and, since the circuit made up of X_c and X_L is approximately tuned to the second harmonic, it is to be expected that the transient oscillations will be those corresponding at least approximately to the natural frequency as dictated by X_c/X_L.

Furthermore, this concept aids greatly in visualizing the production of subharmonics as well as the second harmonics. Consider the equivalent circuit as operating in a steady-state condition with switch S open. Then assume that on some half-cycle, saturation is to be introduced in accordance with the preceding theory. This will mean that switch S must be closed when i reaches 0.9 of the crest value it had been reaching on previous half-cycles. This instant can also be defined with respect to the fundamental-frequency voltage wave. Following the closing of the switch, a high peak of current will flow momentarily, and, when the total i returns to 0.9, switch S will be opened. This will leave a natural frequency oscillation in the circuit, and, when the current i has gone through zero and reaches a value of 0.9 again, switch S

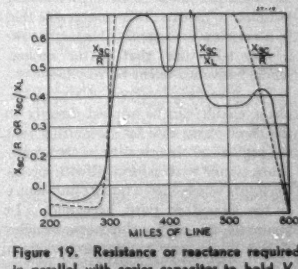


Figure 19. Resistance or reactance required in parallel with series capacitor to hold V_R down to unity for $E \leq 1.1$

X_{sc} = reactance of series capacitors
X_L = reactance in parallel with X_{sc}
R = resistance in parallel with X_{sc}

Other system constants as in Figure 4a

50 per cent series-capacitor line-reactance drop compensation at the mid-point of the line

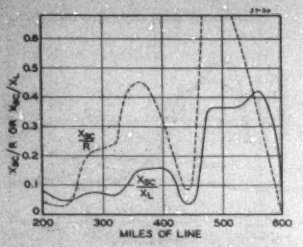


Figure 20. Resistance or reactance required in parallel with series capacitors to hold V_R down to unity for $E \leq 1.1$

X_{sc} = reactance of series capacitors
X_L = reactance in parallel with X_{sc}
R = resistance in parallel with X_{sc}

Second harmonic shunt at receiving-end transformer terminals. Shunt made up of 2,000 ω inductance in series with 0.32-microfarad capacitance wye-connected and ungrounded. Other system constants as in Figure 4a. 50 per cent series-capacitor line-reactance drop compensation at the mid-point of the line

must be closed. This time, however, the instant of closing is not the same with respect to the fundamental-frequency voltage wave as it was on the first half-cycle because of the transient condition. However, the switch must be opened again when the current decreases to 0.9 in accordance with our criterion. Furthermore, the next half-cycle will likely require that switch S be closed at still a different point on the voltage wave so that several cycles may elapse before two cycles are identical or nearly identical. Consequently subharmonics must appear, and the lowest subharmonic will be that corresponding to the period in cycles of fundamental frequency required for the exact initial conditions of closing switch S to repeat. It is conceivable that in a very low loss circuit, this might take a very long time, that is, the subharmonic frequency might be very low.

The preceding analysis of the single-phase circuit can be applied directly to the three-phase case by recognizing that the regions of abnormality in the single-phase circuit were associated with circuit constants which offered infinite impedance to the second or third harmonics. In Figure 24, the relationship between miles of line and source reactance for which

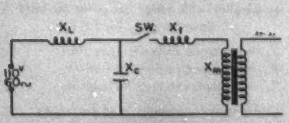


Figure 21. Single-phase lumped-constant circuit studied

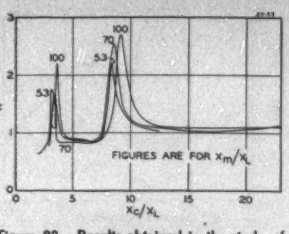


Figure 22. Results obtained in the study of the circuit shown in Figure 21

infinite impedance is offered to harmonics is shown. Also the region in which V_R was found to be greater than unity (from Figure 6) is shown. It is significant that this region is close to the curve giving the relationship between miles of line and source reactance which offers infinite impedance to the second harmonic. Thus it corresponds to the single-phase case which for X_c/X_L slightly less than 4 gave rise to overvoltages of a similar nature. Furthermore, the maximum values of overvoltage in the single-phase case occurred when X_c/X_L was slightly less than 4. This meant that the impedance of the system was actually capacitive. In Figure 24, the region of abnormality lies above the line defining infinite impedance to the second harmonic. This also means that the reactance in this region is capacitive, thus further establishing the similarity between the three-phase and the single-phase case.

In Figure 24, a curve is shown for infinite impedance to the third harmonic. Infinite impedance to the third harmonic occurs naturally for shorter line lengths than for the second harmonic for a given source reactance. However, with a receiving-end transformer having a closed delta, the third harmonic is not necessarily supplied from the line, and therefore the system impedance has little effect. If the receiving-end transformer had no closed delta, then a region of overvoltages should be expected here of third-harmonic nature corresponding to the case of X_c/X_L slightly less than 9.0 in Figure 22. This region does exist but is considered of little practical significance in connection with this paper and so is not included in the curves.

The question as to why the delta being opened or closed made little difference in the phenomenon is answered in Figure 24. Curves showing the relationship between miles of line and source reactance for zero impedance viewed from the receiving end are shown. The curve for zero impedance to the third harmonic is shown to fall partially within the region of abnormality, near its upper extremity. Thus in the abnormal region the system offers a low impedance to third-harmonic currents, and it makes little difference whether the receiving-end transformer has a closed delta or not, since in either case third-harmonic current can easily be supplied.

The preceding discussion would not be complete without some mention of why the second-harmonic shunt is so effective in reducing the abnormal condition in the long lines case. In the single-phase case, the third-harmonic region of overvoltages could be eliminated by a third-harmonic resonant shunt, while the second-harmonic region could be eliminated by a second-harmonic shunt. By analogy between the single-phase and three-phase circuits it is evident that the abnormal region shown in Figure 24 or Figure 6 can be eliminated by a second-harmonic shunt. Furthermore, for reasons just mentioned, with the delta closed, no region of abnormality appears for the third harmonic. Consequently, for the delta closed condition, which is the practical case, a second-harmonic shunt is completely effective in eliminating the abnormal condition brought about by exciting power transformers through long lines.

The preceding analysis has dealt with only the second and third harmonics. Higher harmonics, when suppressed by systems offering infinite impedance to them will produce voltage distortions, but the overvoltages produced will in general be of no practical significance as compared to the phenomena as discussed in this paper.

While the foregoing discussion has dealt primarily with long lines carrying magnetizing currents, it is possible that

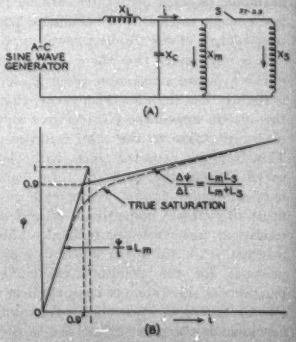


Figure 23. Equivalent circuit (system of Figure 21) for visualizing the underlying cause of the phenomenon

the phenomena observed may be encountered in other cases when the load requires harmonic currents to flow through long lines or from sources which tend to suppress them.

When series capacitors are present, the impedance of the system viewed from the receiving-end transformer terminals remains only slightly changed as far as harmonics are concerned. This is readily understood, because with any practical series-capacitor compensation the reactance of the series capacitor varies inversely as the frequency. Consequently, in the region which caused voltage instability without series capacitors, it is to be expected that instability of the same type will be found with series capacitors. In addition, the presence of series capacitors introduces the possibility of series resonant conditions in a nonlinear circuit consisting essentially of source and line reactance, series capacitor, and saturable reactor (transformer) which accounts for the broadening of the region of abnormality shown in Figure 17. This circuit has been discussed in the technical press, and its behavior is generally well understood.[4-6] It generally requires some form of "shock" excitation in order for the subharmonics to appear. That is, there are several modes of ultimate behavior depending on the initial conditions. This is in contrast to the phenomenon characteristic of the circuit shown in Figure 21 which is discussed in this paper and which generally does not require shock excitation for the phenomenon to appear. The harmonics and subharmonics appear spontaneously, within a few cycles generally, and represent the only mode of steady-state behavior for the circuit. That is, the circuit can respond only in accordance with the curves of Figures 4a and 4b whether the system voltage is raised gradually or whether the system is suddenly energized.

Appendix I

In the equivalent circuit of Figure 19, the per-unit current i_s (base current $= 1/L_m$) through the switch following the closing of it at an initial angle θ after a positive voltage crest (assumed to the unity) is

$$i_{s1} = A_1 \sin(t+\theta_1) + B_1 \sin(\omega_C t + \phi_1) + D_1 \quad (1)$$

where

$$A_1 = \frac{X_m(\omega_o^2-1)}{X_s(\omega_C^2-1)}$$

$$B_1 = \frac{X_m(\omega_o^2-\omega_C^2)}{X_s\omega_C^2(1-\omega_C^2)} \sqrt{\sin^2\theta_1 + \omega_C^2\cos^2\theta_1}$$

$$D_1 = -\frac{X_m\omega_o^2 \sin\theta_1}{X_s\omega_C^2}$$

$$\omega_o = \sqrt{\frac{X_C(X_m+X_L)}{X_mX_L}}$$

the circuit natural frequency in per unit with switch S open

$$\omega_C = \sqrt{\frac{X_C(X_sX_m+X_sX_L+X_mX_L)}{X_mX_LX_s}}$$

the circuit natural frequency in per unit with the switch S closed

$$\sin\phi_1 = \frac{\sin\theta_1}{\sqrt{\sin^2\theta_1+\omega_C^2\cos^2\theta_1}}$$

$$\cos\phi_1 = \frac{\omega_C\cos\theta_1}{\sqrt{\sin^2\theta_1+\omega_C^2\cos^2\theta_1}}$$

The current i flowing into the equivalent transformer is

$$i_{c1} = A_1' \sin(t+\theta_1) + B_1' \sin(\omega_C t+\phi_1) + D_1' \quad (2)$$

where

$$A_1' = \left(1+\frac{X_s}{X_m}\right)A_1$$

$$B_1' = \left(1+\frac{X_s}{X_m}\right)B_1$$

$$D_1' = \sin\theta_1 + \left(1+\frac{X_s}{X_m}\right)D_1$$

The voltage across the capacitor is

$$e_{c1} = F_1\cos(t+\theta_1) + G_1\cos(\omega_C t+\phi_1) \quad (3)$$

where

$$F_1 = \frac{(\omega_o^2-1)}{(\omega_C^2-1)}$$

$$G_1 = \frac{(\omega_o^2-\omega_C^2)}{\omega_C(1-\omega_C^2)} \sqrt{\sin^2\theta_1+\omega_C^2\cos^2\theta_1}$$

Interrupting the current i_s, the voltage across the capacitor is

$$e_{c1} = \cos(t+\theta_1') + H_1\sin\omega_o t + J_1\times\cos(\omega_o t+\alpha_1) + K_1\cos(\omega_o t+\beta_1) \quad (4)$$
$$= \cos(t+\theta_1') + M_1\cos(\omega_o t+\Sigma)$$

where

$$H_1 = \frac{(\omega_o^2-\omega_C^2)\omega_o\sin\theta_1}{\omega_C^2}$$

$$J_1 = \frac{(\omega_o^2-\omega_C^2)}{\omega_C^2(1-\omega_C^2)} \sqrt{\sin^2\theta_1+\omega_C^2\cos^2\theta_1}\times \sqrt{\omega_C^2\cos^2\delta_1+\omega_o^2\sin^2\delta_1}$$

$$K_1 = \frac{(\omega_o^2-\omega_C^2)}{(\omega_C^2-1)} \sqrt{\cos^2\theta_1' + \omega_o^2\sin^2\theta_1'}$$

$$\delta_1 = \omega_C t_{c1} + \phi_1$$
$$\theta_1' = t_{c1} + \theta_1$$

t_{c1} is the interval of time in radians during which the switch was closed

$$\sin\alpha_1 = \frac{\omega_o\sin\delta_1}{\sqrt{\omega_C^2\cos^2\delta_1+\omega_o^2\sin^2\delta_1}}$$

$$\cos\alpha_1 = \frac{\omega_C\cos\delta_1}{\sqrt{\omega_C^2\cos^2\delta_1+\omega_o^2\sin^2\delta_1}}$$

$$\sin\beta_1 = \frac{\omega_o\sin\theta_1'}{\sqrt{\cos^2\theta_1' + \omega_o^2\sin^2\theta_1'}}$$

$$\cos\beta_1 = \frac{\cos\theta_1'}{\sqrt{\cos^2\theta_1'+\omega_o^2\sin^2\theta_1'}}$$

The current i becomes

$$i_{s1} = \sin(t+\theta_1) - \frac{H_1}{\omega_o}\cos\omega_o t + \frac{J_1}{\omega_o}\times \sin(\omega_o t+\alpha_1) + \frac{K_1}{\omega_o}\sin(\omega_o t+\beta_1) \quad (5)$$

Closing the switch at the next instant when the current i reaches the critical value

$$i_{s2} = A_1\sin(t+\theta_1) + B_2\sin(\omega_C t+\phi_2) + D_2 + M_1S_2\sin(\omega_C t+\psi_2) + W_2M_1 \quad (6)$$

A_1 defined in equation 1

$$B_2 = \frac{X_m(\omega_o^2-\omega_C^2)}{X_s\omega_C^2(1-\omega_C^2)} \sqrt{\sin^2\theta_2+\omega_C^2\cos^2\theta_2}$$

$$D_2 = -\frac{X_m\omega_o^2\sin\theta_2}{X_s\omega_C^2}$$

$$\theta_2 = t_{s1}+t_{c1}+\theta$$

$$\sin\phi_2 = \frac{\sin\theta_2}{\sqrt{\sin^2\theta_2+\omega_C^2\cos^2\theta_2}}$$

$$\cos\phi_2 = \frac{\omega_C\cos\theta_2}{\sqrt{\sin^2\theta_2+\omega_C^2\cos^2\theta_2}}$$

$$S_2 = \frac{X_m}{\omega_C^2X_s} \sqrt{\omega_o^2\sin^2\Delta_2+\omega_C^2\cos^2\Delta_2}$$

$$\sin\psi_2 = \frac{\omega_o\sin\Delta_2}{\sqrt{\omega_o^2\sin^2\Delta_2+\omega_C^2\cos^2\Delta_2}}$$

$$\cos\psi_2 = \frac{\omega_C\cos\Delta_2}{\sqrt{\omega_o^2\sin^2\Delta_2+\omega_C^2\cos^2\Delta_2}}$$

Δ_2 = angle of ω_o frequency voltage past positive voltage crest when switch is closed

$$W_2 = -\frac{X_m\omega_o\sin\Delta_2}{X_s\omega_C^2}$$

The voltage across the capacitor is

$$e_{c2} = \frac{X_s}{X_m}\frac{di_{s2}}{dt}$$

and the current i_{c2} into the equivalent transformer is of the form of equation 2.

At the time of interruption, the current i_{c2} takes the form of equation 5 subject to the new boundary conditions. The voltage e_{c2} takes the form of equation 4 also subject to the new boundary conditions.

This procedure can go on for as long as desired, each time imposing the new boundary conditions. It can be seen readily that these successive boundary conditions will not in general be the same for adjacent cycles of fundamental frequency. That is $\theta_1+\pi \neq \theta_2$, $\theta_2+\pi \neq \theta_3$, ... $\theta_n+\pi \neq \theta_{n+1}$. Ultimately, however, $\theta_n+a\pi = \theta_{n+a}$ and a definite subharmonic frequency will appear. Furthermore, the voltage oscillation across the capacitor will be of fundamental frequency plus a natural-frequency oscillation which is predominantly that defined as ω_o, the natural frequency of the system with the switch open. This is brought about by the

fact that the switch S is closed in general only a short fraction of a fundamental-frequency period, and that period is generally in the vicinity of fundamental-frequency voltage zero. Therefore, it is to be expected that when circuit losses are low, the natural frequency of the circuit with the switch open and subharmonics will appear across the capacitor in the circuit of Figure 23.

Appendix II

Viewed from the receiving end, the system of Figure 1 or 2 neglecting losses offers an impedance[8]

$$Z_r = j\frac{\omega L_s \cos \omega l\sqrt{LC} + \sqrt{\frac{L}{C}} \sin \omega l\sqrt{LC}}{\cos \omega l\sqrt{LC} - \omega L_s \sqrt{\frac{C}{L}} \sin \omega l\sqrt{LC}} \quad (1)$$

where

L = inductance per mile in henrys
C = capacitance per mile in farads
L_s = source inductance in henrys
$\omega = 2\pi f$
l = length of line in miles

In the transient-analyzer artificial line

$L = 0.002$ henry per mile
$C = 0.016$ microfarad per mile

For $Z_r = \infty$, the criterion is

$$\cos \omega l\sqrt{LC} - \omega L_s \sqrt{\frac{C}{L}} \sin \omega l\sqrt{LC} = 0 \quad (2)$$

or, rewriting

$Zr = \infty$

when

$$\tan \omega l\sqrt{LC} = \frac{1}{\omega L_s}\sqrt{\frac{L}{C}} \quad (3)$$

This equation was used with the above numerical constants for plotting the curves relating source reactance and miles of line to give infinite impedance in Figure 20.

For $Z_r = 0$, the criterion is

$$\omega L_s \cos \omega l\sqrt{LC} + \sqrt{\frac{L}{C}} \sin \omega l\sqrt{LC} = 0 \quad (4)$$

or, rewriting

$Z_r = 0$

when

$$\omega l\sqrt{LC} = -\omega L_s \sqrt{\frac{C}{L}} \quad (5)$$

This equation was used with the above numerical constants for plotting the curves relating source reactance and miles of line to give zero impedance in Figure 24.

It can also be shown that the relationship between source reactance ωL_s and line length to give infinite impedance is independent of the point considered along the line. If l is the total length of line considered, and d is the distance between the

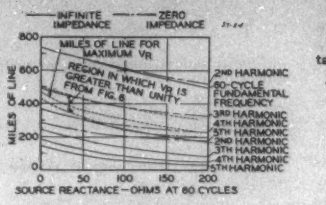


Figure 24. Relationship between miles of line and source reactance which offers infinite or zero impedance to harmonics viewed from any point along the line

Resistance neglected

sending end and the point from which the impedance is to be determined, then

$$Z = \frac{-j\sqrt{\frac{L}{C}}\cot \omega(l-a)\sqrt{LC}\cdot j\times\left[\frac{\omega L_s \cos \omega l\sqrt{LC} + \sqrt{\frac{L}{C}} \sin \omega l\sqrt{LC}}{\cos \omega l\sqrt{LC} - \omega L_s \sqrt{\frac{C}{L}} \sin \omega l\sqrt{LD}}\right]}{-j\sqrt{\frac{L}{C}}\cot \omega(l-d)\sqrt{LC} + j\times\left[\frac{\omega L_s \cos \omega l\sqrt{LC} + \sqrt{\frac{L}{C}} \sin \omega l\sqrt{LC}}{\cos \omega l\sqrt{LC} - \omega L_s \sqrt{\frac{C}{L}} \sin \omega l\sqrt{LC}}\right]}$$

$$= \frac{-\sqrt{\frac{L}{C}}\cot \omega(l-d)\sqrt{LC}\times\left[\frac{\omega L_s \cos \omega l\sqrt{LC} + \sqrt{\frac{C}{L}} \sin \omega l\sqrt{LC}}{\left[-\sqrt{\frac{L}{C}}\cot \omega(l-d)\sqrt{LC}\right]\times\left[\cos \omega l\sqrt{LC} - \omega L_s \sqrt{\frac{C}{L}} \sin \omega l\sqrt{LC}\right]\times}\right]}{\omega L_s \cos \omega l\sqrt{LC} + \sqrt{\frac{L}{C}} \sin \omega l\sqrt{LC}} \quad (6)$$

$Z = \infty$ when the denominator of equation 6 is zero. Rewriting this denominator

$$-\sqrt{\frac{L}{C}}\cot \omega(l-d)\sqrt{LC}\cdot\cos \omega l\sqrt{LC} + \omega L_s \cot \omega(l-d)\sqrt{LC}\cdot \sin \omega l\sqrt{LC} + \omega L_s \cos \omega l\sqrt{LC} + \sqrt{\frac{L}{C}} \sin \omega l\sqrt{LC}$$

$$= -\sqrt{\frac{L}{C}}\cos \omega l\sqrt{LC}\times\frac{1+\tan \omega l\sqrt{LC}\tan \omega d\sqrt{LC}}{\tan \omega l\sqrt{LC} - \tan \omega d\sqrt{LC}} + \omega L_s \times \sin \omega l\sqrt{LC}\,\frac{1+\tan \omega l\sqrt{LC}\tan \omega d\sqrt{LC}}{\tan \omega l\sqrt{LC} - \tan \omega d\sqrt{LC}} + \omega L_s \cos \omega l\sqrt{LC} + \sqrt{\frac{L}{C}}\sin \omega l\sqrt{LC} = 0$$

$$-\sqrt{\frac{L}{C}}\cos \omega d\sqrt{LC} - \sqrt{\frac{L}{C}}\cos \omega d\sqrt{CL}\times \tan \omega l\sqrt{LC}\tan \omega d\sqrt{LC} + \omega L_s \sin \omega d\sqrt{LC} + \omega L_s \sin \omega d\sqrt{LC}\tan \omega l\sqrt{LC}\tan \omega d\sqrt{LC} + \omega L_s \cos \omega d\sqrt{LC}\tan \omega l\sqrt{LC} - \omega L_s \cos \omega d\sqrt{LC}\tan \omega d\sqrt{LC} + \sqrt{\frac{L}{C}}\sin \omega d\sqrt{LC}\tan \omega l\sqrt{LC} - \sqrt{\frac{L}{C}}\sin \omega d\sqrt{LC}\tan \omega d\sqrt{LC} = 0$$

$$\omega L_s[\sin \omega d\sqrt{LC} + \sin \omega d\sqrt{LC}\tan \omega l\sqrt{LC}\times \tan \omega d\sqrt{LC} + \cos \omega d\sqrt{LC}\tan \omega l\sqrt{LC} - \cos \omega d\sqrt{LC}\tan \omega d\sqrt{LC}] = \sqrt{\frac{L}{C}}[\cos \omega d\sqrt{LC} + \cos \omega d\sqrt{LC}\tan \omega l\sqrt{LC}\tan \omega d\sqrt{LC} - \sin \omega d\sqrt{LC}\tan \omega l\sqrt{LC} + \sin \omega d\sqrt{LC}\tan \omega d\sqrt{LC}]\omega L_s \times \tan \omega l\sqrt{LC}[\sin \omega d\sqrt{LC}\tan \omega d\sqrt{LC} + \cos \omega d\sqrt{LC}] = \sqrt{\frac{L}{C}}[\cos \omega d\sqrt{LC} + \sin \omega d\sqrt{LC}\tan \omega d\sqrt{LC}]$$

and finally $\tan \omega l\sqrt{LC} = \frac{1}{\omega L_s}\sqrt{\frac{L}{C}}$

which is identical with equation 3, which was to be proved.

Similarly it can be shown that the condition for $Z = 0$ as given by equation 4 holds for any location along the line.

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Self-Excited Oscillations of Capacitor-Compensated Long-Distance Transmission Systems

R. B. BODINE
ASSOCIATE AIEE

C. CONCORDIA
MEMBER AIEE

G. KRON
ASSOCIATE AIEE

THE transmission of electric power over long distances has been the subject of considerable study,[1] and it has been concluded that an effective way of increasing the permissible straightaway transmission distance is by means of series-capacitor compensation of part of the transmission-line inductive reactance. The introduction of longer lines together with capacitor compensation brings up several technical problems which must be considered if proper operation is to be assured. Studies of transient stability and switching times following faults and of abnormal overvoltages which may result from interaction of line capacitance and transformer exciting impedance at no load are presented in references 2 and 3 respectively. This paper presents the results of a study of hunting and self-excitation during normal operation as affected by line and machine characteristics.

Previous work[4] and field experience have indicated the possibility of self-excited oscillations when synchronous machines are connected to capacitor-compensated circuits. It has been shown[5] that a high ratio of line resistance to reactance reduces the machine damping torque, and that the compensation of the line reactance by means of series capacitors increases the effective value of this ratio. It has also been shown[4,6,7] that series-capacitor compensation of line reactance may lead to self-excited electrical oscillations as well as to mechanical rotor oscillations (hunting) under certain circuit conditions.

The series-capacitor-compensated long-distance transmission system is somewhat difficult to analyze directly in terms of previously developed criteria, as in this case there is a considerable distributed shunt capacitance in addition to the series capacitance. This shunt capacitance has been neglected in previous mathematical analyses because of the analytical difficulties involved as well as for the reason that in the previously considered application to distribution circuits[4] the shunt capacitance was relatively small and unimportant. Setting up and solving directly the complete differential equations of the system including a synchronous generator and compensated transmission line are impractical, if the transmission line is represented with any reasonable degree of exactness, as the order is extremely high. The alternative of setting up and studying a laboratory model, as reported in a recent paper[8] and as was done in a previous unpublished study, was not considered desirable because of the difficulty of varying system parameters. Instead it seemed preferable to develop and apply the method of equivalent circuits, using the a-c network analyzer, which had already shown itself to be of practical value in other related studies.[9,10] The equivalent-circuit method has the advantage of ease of varying system parameters over a wide range, as in mathematical analyses, but with a minimum of calculation, as in model testing, since most of the results can be read directly on instruments. The network analyzer is particularly convenient, compared to hand calculations, in the necessary setting up of initial conditions, that is, machine excitations, fluxes, currents, and so forth, which vary with practically every change of any system parameters for a specified system load angle, or other condition.

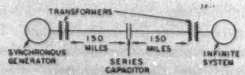


Figure 1. Series-capacitor-compensated transmission system

Transformer reactance = ten per cent (each)
Line reactance = 0.8 ohm per mile
Line resistance = 0.08 ohm per mile
Line capacitance = 5.2×10^{-6} mho per mile
Generator x_d = 110 per cent, x_q = 74 per cent
x_d' = 37.7 per cent
x_d'' = 28.1 per cent, x_q'' = 39.3 per cent (with amortisseur)
Base kilovolt-amperes = $2.5 \times$ (kv)^2

Conclusions

1. A method of attack using equivalent circuits set up on the a-c network analyzer has been developed which enables one to predetermine from an equivalent circuit the possibility of self-excited oscillations in generators connected to series-capacitor-compensated long-distance transmission lines. A detailed study of any proposed installation can be made by this method, if it appears necessary from a preliminary inspection.

2. In the range of transmission line studied (up to 300 miles and fully compensated) hunting can be prevented by a proper generator amortisseur without encountering electrical self-excitation. An amortisseur is necessary if hunting is to be avoided under all conditions, but self-excitation will not occur unless the line resistance is lower than for usual practical transmission lines.

3. Rotor inertia has little effect on the significant regions of electrical self-excitation.

Procedure

Equivalent circuits for the synchronous generator and for the compensated transmission line during oscillations are developed and described in the companion paper[11] and in reference 12, respectively. Only the procedure used in applying the method to the network analyzer will be discussed here.

The system for which results are presented is shown in Figure 1. It consists of a 300-mile transmission line terminated at both ends by a transformer of ten per cent reactance. A generator having the electrical characteristics of an average water-wheel generator is connected through the transmission line and transformers to an infinite bus. The damping and synchronizing torque coefficients T_d and T_s for a range of oscillation frequencies h have been obtained for several cases. The limits of stable operation are determined in terms of the stable ranges of generator inertia as follows.

For the generator, the torque equation during sinusoidal rotor oscillations may be expressed as:

$$(-Mh^2 + jhT_d + T_s)\Delta\delta = \Delta T \qquad (1)$$

where

M = generator rotor inertia, per unit = $4\pi fH$
h = oscillation frequency, per unit
$\Delta\delta$ = rotor angular oscillation
ΔT = applied torque required to produce the oscillation $\Delta\delta$

Paper 43-8, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted October 19, 1942; made available for printing November 2, 1942.

R. B. BODINE and C. CONCORDIA are with the central station engineering department, and G. KRON is consulting engineer, all with General Electric Company, Schenectady, N. Y.

The authors acknowledge the assistance of S. B. Crary, J. E. Paul, W. Ridgway, C. G. Adams, and J. M. Perry in obtaining the results reported in this paper.

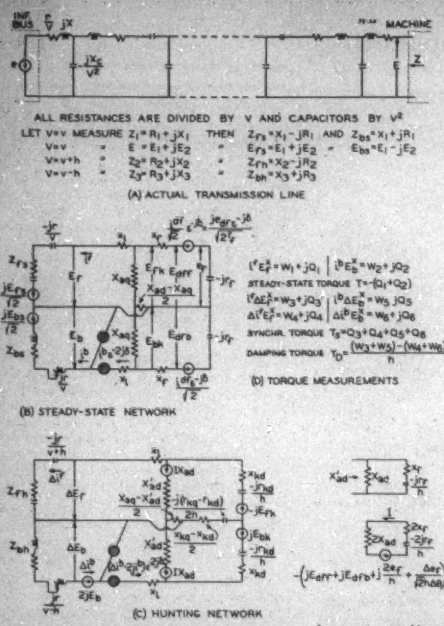


Figure 2. Equivalent circuits for transmission line connected to salient-pole synchronous machine

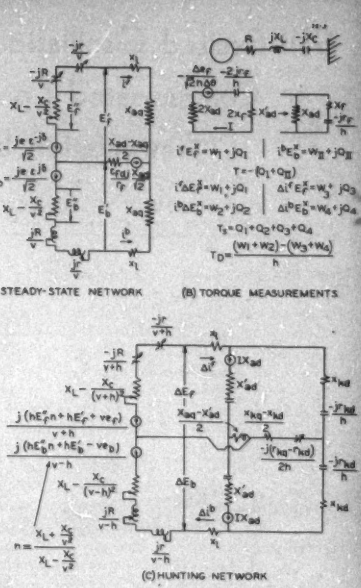


Figure 3. Equivalent circuits for salient-pole synchronous machine connected to infinite bus through R-L-C tie

At the boundary between stable and unstable oscillations the total rotor torque must be zero ($\Delta T = 0$). Equation 1 then shows that T_d must be zero, and T_s must equal h^2M (or M must equal T_s/h^2). Thus at each point where T_d crosses zero, a limiting value of M may be found. For low values of h and positive T_s it has previously been shown that the system is unstable for negative values of T_d. This provides the information required to distinguish between the stable and unstable ranges of rotor inertia. The magnitude of the negative damping torque coefficient T_d also provides a measure of the degree of instability, just as the magnitude of the positive damping torque coefficient is a measure of the amount of negative damping which can be tolerated in the system. In the region of high oscillation frequency no such simple and foolproof criterion of stability can be found.

From the previous studies (references 4, 6, 7, 13), it is known that electrical self-excitation may occur even aside from rotor oscillations, that is, even with infinite rotor inertia. In this case the electrical-network effective impedance becomes zero[14] at the self-excited oscillation frequency, and the torque developed becomes infinite. If, however, the system will not self-excite except with a finite rotor inertia M, the limiting value of M may be found as described above. With any reasonable value of M the torques in the region of self-excitation are extremely great, and the transition from stable to unstable operation can thus easily be detected.

The equivalent circuits required are shown in detail in references 11, 12, and 15. Figure 2 shows the circuits as applied to the present case. Two points are to be noted in connection with the procedure used. First, the equivalent circuit for the transmission line is set up separately and its characteristic impedances and terminal voltages determined as indicated in Figure 2a over the desired range. These values are then used in the equivalent circuit for the synchronous machine, Figures 2b and 2c. Second, since the machine equivalent circuit as developed in references 12 and 15 can be so adjusted as to contain both positive and negative resistances but no capacitance, all impedance values are multiplied by a factor $-j$, resulting in the circuit shown in Figures 2b and 2c, which contains inductance, capacitance, and positive resistance over a good part of the range. The torque formulas undergo a similar transformation, as may be seen by comparing Figure 2d with the formulas of reference 12. For large values of the oscillation frequency h (that is, for $h > (1-\sqrt{x_c/x_t})$ approximately, where x_t is the total line, transformer and machine armature leakage reactance), the impedance Z_{bb} of Figure 2c has a negative-resistance component X_s. These cases were handled by a method of superposition, by first measuring the circuit impedance viewed from the Δi^3 mesh and then making the necessary additional calculations by hand.

Results

Figures 4–7 show some of the results obtained.

Figure 4 gives damping and synchronizing torques for the system with line capacitance neglected. Here there is no possibility of purely electrical self-excitation, but it is seen that for oscillation frequencies in the range $0.5 < h < 1.0$ the damping torque coefficient is negative, so that hunting will occur for rotor inertias which give natural frequencies in this range. From the formula $M = T_s/h^2$, applied at the points of zero damping, the

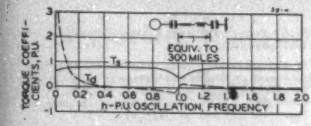


Figure 4. Damping and synchronizing torque coefficients for synchronous machine connected to infinite bus through series resistance and reactance—at no load and with amortisseur

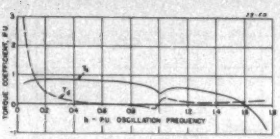
range of rotor inertias for which the system is unstable is $0.43 < M < 3.24$, or in terms of the conventional inertia constant $H (M = 4\pi f H)$, $0.00057 < H < 0.0043$. These values are extremely small and entirely outside of any practical range, so the conclusion is that the system is stable. This would be expected for the machine considered, since it has an amortisseur.

Figure 5 shows the effect of varying the amount of series-capacitor compensation for the same system as in Figure 4 but now considering the transmission-line capacitance. The line capacitance does not by itself affect the range of negative damping very much, as may be seen by comparing Figure 5a with Figure 4a. Figures 5b to 5d show that one effect of series-capacitor compensation is to extend the lower limit of rotor inertia for which the system is unstable to zero, as seen by the fact that T_s becomes zero while T_d is still negative. However, the upper limit is still extremely small; in the most severe case of full compensation of line and transformer reactance ($x_c = 0.8$, Figures 5d and 5h) the greatest rotor inertia for which the system will be unstable is $M = T_s/h^2 = 5.05/(0.19)^2 = 140$, or $H = 0.186$.

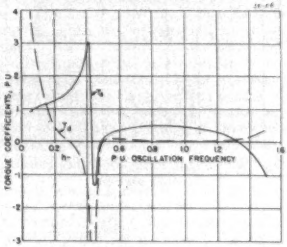
The fact that T_s becomes negative and that resonance points in both T_d and T_s occur at high oscillation frequencies does not mean that the system is unstable. The curves of hT_d versus T_s given in Figures 5e to 5h are useful in this respect as they exhibit a remarkable regularity, forming more or less circular curves in the resonance regions and thus serving as a good indication of the magnitude of the torque coefficients and the probable form of the T_d and T_s versus h curves in these regions.

Figure 6 is similar to Figure 5 but for a generator with no amortisseur. The damping now becomes negative at a much lower oscillation frequency, corresponding to a rotor inertia approaching practical values; Figure 7 shows the effect of load angle on the system of Figure 6. Even with 75 per cent load on the generator the system is still unstable at rather low oscillation frequencies.

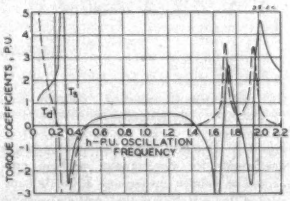
In all of the cases considered above



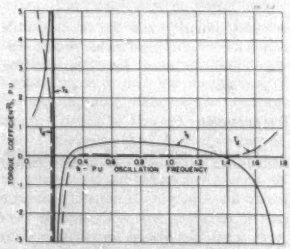
(a). No compensation, $x_c = 0$ (see Figure 5e)



(b). With series-capacitor compensation, $x_c = 40$ per cent (see Figure 5f)



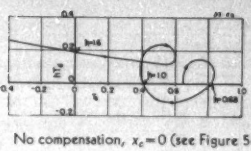
(c). With series-capacitor compensation, $x_c = 60$ per cent (see Figure 5g)



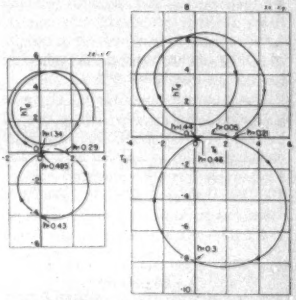
(d). With series-capacitor compensation, $x_c = 80$ per cent (see Figure 5h)

Figure 5. Damping and synchronizing torque coefficients for synchronous machine connected to infinite bus through 300-mile transmission line—at no load and with amortisseur

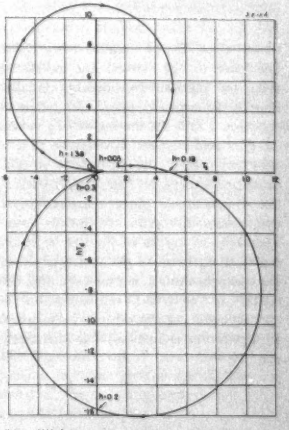
the armature and line resistance are so high that electrical self-excitation does not occur, in spite of the fact that a rather low ($r/x = 10$ per cent) line resistance was assumed. Previously[13] it had been concluded that the line resist-



(e). No compensation, $x_c = 0$ (see Figure 5a)

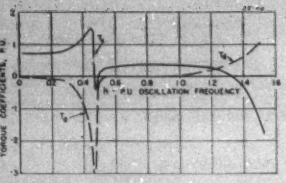


(f) (left). With series-capacitor compensation, $x_c = 40$ per cent (see Figure 5b)
(g) (right). With series-capacitor compensation, $x_c = 60$ per cent (see Figure 5c)

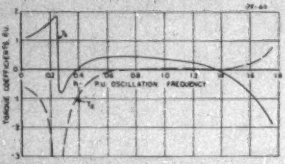


(h). With series-capacitor compensation, $x_c = 80$ per cent (see Figure 5d)

ance below which self-excitation could exist with infinite rotor inertia and zero shunt line capacitance was well below the actual probable value. The results presented above lead to this same conclusion for an actual line and considering rotor inertia. As a quantitative check of the effect of rotor inertia the case of Figure 2, reference 12, has been set up and studied by the equivalent-circuit method, using the circuit of Figure 3. The results obtained show that the introduction of a



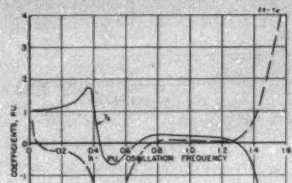
(a). With series-capacitor compensation, $x_c = 40$ per cent



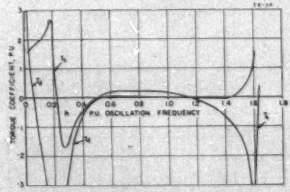
(b). With series-capacitor compensation, $x_c = 80$ per cent

Figure 6. Damping and synchronizing torque coefficients for synchronous machine connected to infinite bus through 300-mile transmission line—at no load and without amortisseur

finite rotor inertia makes very little difference in the critical line resistance even for inertias considerably smaller than could actually exist. In terms of equation 1 and the curves of hT_d versus T_s, it is evident that T_s must be practically infinite at the boundary of self-excitation except for very small oscillation frequency h, since reasonable per unit values of inertia are always large. The series of curves of Figures 5e to 5h shows the growth of the lower circle as the compensation x_c is increased and the region of electrical self-excitation is approached. At the critical value when self-excitation is just possible this circle



(a). With series-capacitor compensation, $x_c = 40$ per cent



(b). With series-capacitor compensation, $x_c = 80$ per cent

Figure 7. Damping and synchronizing torque coefficients for synchronous machine connected to infinite bus through 300-mile transmission line—at 75 per cent load and without amortisseur

becomes infinite, and in the unstable region it curves upward rather than downward and so does not intersect the $hT_d = 0$ axis.

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Dielectric-Recovery Characteristics of Large Air Gaps

G. D. McCANN
ASSOCIATE AIEE

J. J. CLARK
ASSOCIATE AIEE

Synopsis: In contrast to power arcs in air, for which the dielectric-recovery voltage decreases with increasing arc current, arcs in air produced by surge currents of several hundred microseconds' duration possess dielectric-recovery characteristics that vary only slightly with current magnitude and wave shape. Even when the discharge current is prolonged at low magnitude for as long as a thousand microseconds, the rate of dielectric recovery is little affected. For this condition at times when current as high as one ampere is flowing, the transient voltage required to convert to a high current arc is quite high. The mechanism for such a discharge is different than for the breakdown of virgin air, and the initial arc drop is sufficiently high to record its transient character. It is about ten times the steady-state value at the time the crest current is reached and drops about 50 per cent in the first 20 microseconds.

Photographic studies show that even at short-time intervals successive discharges do not follow exactly the path blazed by the initial discharge but occur in an air column of low dielectric strength expanding radially with time. It is indicated that the high arc temperatures diffusing in this region can be the principal factor determining the rate of recovery after the first 1,000 microseconds.

A comparison is made with the mechanism of natural lightning particularly from recent data obtained on the low-magnitude portions of stroke currents between successive components. Such records show that current does not always flow continuously between multiple-stroke components for strokes to objects of normal height. The maximum interval of recorded zero current is about 23,000 microseconds. The rates of recovery for spark gaps indicate that about 40,000 microseconds is the upper limit for which the dielectric strength of the stroke channel will be sufficiently low to insure successive breakdown in the same general region.

The character of a lightning discharge initiating a power follow does not affect the rate of recovery after the power arc has been extinguished. Circuit reclosing times should be based primarily on the probability of the duration of multiple strokes and the probability of restriking for power arcs.

Correlation of the rate of dielectric recovery of air gaps with rates of system recovery show that an appreciable number of transmission-line lightning flashovers can occur at such a time relative to the normal system voltage cycle that only a very short-duration fault is produced. The number is about 10 to 15 per cent for a typical system having a natural period of 1,000 cycles which corresponds to a line about 40 miles in length. This is about half of the flashovers which normally do not cause outages. The rest are due to cases where power arcs longer than one cycle are produced but extinguish before a circuit-breaker operation.

THE rates at which large air gaps recover dielectric strength after discharging power-frequency currents and short-duration surge currents comparable to those produced by lightning are of fundamental importance in determining power-system performance. Some of the more important considerations are the factors governing the probability of lightning flashovers producing power follow, the probability of power follow producing an outage, and the minimum safe reclosing time after a circuit interruption. Because of the similarity between long arcs and the mechanism of natural lightning, data on the electrical characteristics of the arc path after an initial discharge and the character of subsequent discharges should also give information on the mechanism of multiple strokes. Despite its fundamental value, very meager data are available on the rates of dielectric recovery of large gaps, especially for initial discharges having the character of lightning currents. Most studies have been confined to power arcs in very small gaps where arc conditions are quite different.

For the study of surge current discharges in large air gaps a method of synchronizing two generators has been developed so that surge current discharges can be produced in a gap and controlled surge voltages applied after specified time intervals. Data have thus been obtained for 6- and 11-inch rod gaps on the voltage necessary to produce a second discharge as a function of the time interval after the first. Eleven inches was the maximum spacing which could be tested with the facilities available. With negative polarity throughout, a wide range of initial current magnitudes and wave shapes was studied, the subsequently applied voltage having the standard $1^1/_2 \times 40$ wave shape. The same terminology (critical voltage), as used for the minimum breakdown in virgin air, is applied to the minimum breakdown after an initial discharge. This should lead to no confusion as long as the time interval after the initial discharge is specified. By raising the voltage above the critical value, volt-time curves were also obtained in the same manner as those for breakdown in virgin air. Through the use of a high-speed rotating camera and still cameras, data were also obtained on the visual characteristics of the initial and subsequent discharges.

Test Circuit

A schematic diagram of the surge generator circuits is shown in Figure 1. The initial discharge through the test gap is produced by the current generator and the subsequently applied potential by the voltage generator. The two generator trip circuits are synchronized by a rotating switch. As shown in Figure 1, the tripping cycle is started by shorting out gap *A*. When the arm of the rotating switch next passes through gap *B* the tripping circuit for the current generator is discharged. When the arm passes through gap *C*, the tripping circuit for the voltage generator is discharged, providing gap *B* is still passing current, which is assured by making the time constant of the first circuit long enough for the desired range of time intervals. In this way the two generators can be discharged only in the proper sequence. The time interval is controlled by the spacing between gaps *B* and *C* and the speed of the rotating arm driven by a variable-speed motor.

During the discharging of the current generator, the voltage generator must be isolated from the test circuit. The gap *D* of Figure 1 must have a higher breakdown value than the test gap, so that the voltage generator will not be prematurely discharged. The larger gap requires a higher discharge voltage than is to be applied to the test gap, and thus, as shown in the figure, only a portion of the generator voltage is tapped from the potentiometer circuit. If the impedance of the current generator is high enough that it does not distort the voltage of the voltage generator discharging through it in parallel with the test gap, the gap *E*

Paper 43-10, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE national technical meeting, New York, N. Y., January 25-29, 1943. Manuscript submitted October 17, 1942; made available for printing November 9, 1942.

G. D. McCANN is transmission engineer in central station engineering department, and J. J. CLARK is section engineer, general laboratories section, both with Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

The authors acknowledge the guidance given by C. F. Wagner, the work of C. M. Lear in obtaining the laboratory data, and the suggestions of R. D. Evans, T. E. Browne, A. P. Strom, W. E. Berkey, and R. C. Mason.

may flash over on the second discharge. However, as most high current generators are of low impedance, gap *E* must have a higher breakdown value than the test gap during the second discharge. If such a large gap spacing will not permit the initial discharge of the current generator, a fiber tube and fuse wire can be used to permit the current generator to discharge before isolating it for the voltage generator discharge.

Dielectric-Recovery Voltage for Initial Discharges of Short Duration

The wave shapes of the initial discharge currents studied can be conveniently classified into two groups. The first group had durations less than 100 microseconds and were short compared to the time interval between the initial discharge and the application of voltage. The second had durations of the same order of magnitude as the time intervals, and at the lower range of intervals current was still flowing when voltage was applied. The shortest time interval between the beginning of the current discharge and the application of voltage that could be consistently reproduced with the rotating gap was about 500 microseconds. The initial discharges of short duration will be considered first. In Figure 2 are given the wave shapes of the currents which were used for the two gap lengths studied. As shown by Figure 2a, the currents for the six-inch gap spacing involved crest magnitudes ranging from 1,390 amperes to 23,000 amperes and charges ranging from 0.002 to 0.238 coulomb. Wave shapes of two general types were used—one in which the high current lasted only a fraction of a microsecond, and the other in which the high current was maintained for five or ten microseconds. This was done to determine the effect of the two factors—magnitude and duration.

The discharges with only instantaneously high currents were produced with a high-voltage generator of low capacity and a high series resistance in the discharge circuit which limited the current flowing from the generator itself to a relatively low value. However, as previous work has shown, the discharge mechanism for large air gaps is quite similar to that of natural lightning.[1-3] The initial current flowing at the electrodes at the breakdown of an air gap is produced by streamers propagating from one or both electrodes and distributing charge along the channel which they blaze. When these two leaders meet, intense "return streamers" are formed which propagate back to the gap electrodes and rapidly discharge the charge in the gap. For applied voltages similar to the standard $1^1/_2 \times 40$ wave, the whole process takes place in less than a microsecond. The high peak in the measured current occurs when the return streamers reach the gap electrodes, and the current which flows for the next fraction of a microsecond depends upon the charge in the air gap. After this initial charge is dissipated, the current is determined by the surge-generator circuit. Thus, for surge generators of low capacity and high discharge resistance, the current rapidly drops to a much lower magnitude designated in Figure 2 as the steady crest magnitude. The current waves *A*, *B*, *D*, and *H* were produced in this way. A high current generator of much greater capacity and lower discharge resistance was used to produce current waves *C*, *E*, *F*, and *I*, for which the sustained current magnitude is approximately the same as the initial crest.

In Figures 3 and 4 are given data obtained on the critical voltage as a function of time interval after the initial discharge, and in Figure 5 are typical volt-time curves. For each time interval these data were obtained in the same manner as normally used for volt-time curves except that no correction was made for atmospheric conditions since the significance of this factor is not known. However, all data were taken under substantially uniform conditions, the relative air density varying between 0.994 and 1.01 and the absolute humidity between 0.152 and 0.426 inch of mercury vapor pressure.

Consistency of Breakdown

Caused principally by variations in ionization conditions, the breakdown of an air gap is not a single fixed value. There is a certain probability which determines the critical breakdown. If virgin air has less ionization than for a given period after an initial discharge, it would be thought that the variation of individual values from the critical would be appreciably less. Although no attempt was made to determine probability curves of breakdown, some information is contained in the data obtained for volt-time curves. For several cases the voltage was first set considerably below the break-

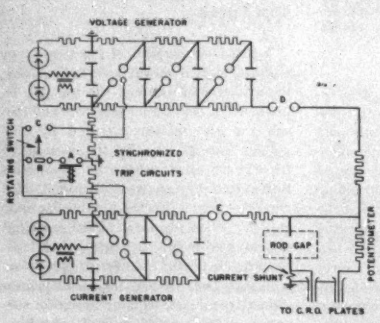


Figure 1. Schematic diagram of surge generators and synchronizing trip circuit

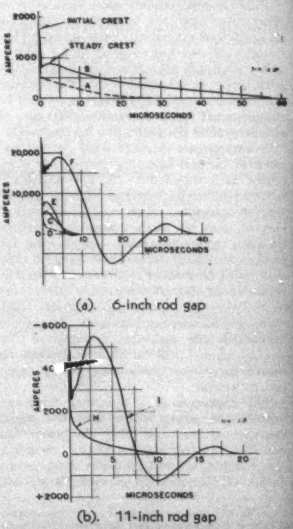
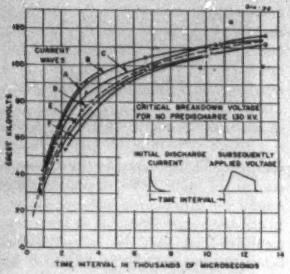
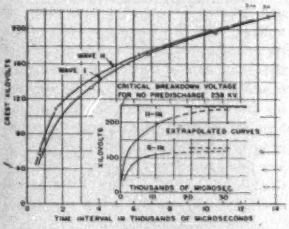


Figure 2. Wave shapes of initial current discharges of short duration. Negative polarity

Wave	Initial Crest Amperes	Steady Crest Amperes	Charge in Coulombs
A	1,390	532	0.005
B	1,710	850	0.009
C	4,780	5,690	0.024
D	5,560	2,000	0.008
E	6,600	7,720	0.038
F	23,000	19,100	0.238
H	4,630	1,400	0.006
I	4,900	5,680	0.034



(a). 6-inch rod gap



(b). 11-inch rod gap

Figure 3. Critical breakdown voltage as function of time after initial discharges of Figure 2

Second applied voltage negative $1^1/_2 \times 40$ wave

down value, then raised in about two per cent steps, taking in some instances five and in others ten shots at each voltage. This provided data on the percentage variation, either in the minimum voltage that would produce breakdown, or the maximum that would not, from the mean or critical breakdown. These data showed, for time intervals below 1,000 microseconds, a maximum variation of about 20 per cent from the critical breakdown. Above 1,000 microseconds the maximum variation was about 13 per cent, and no trend was observed with time interval. However, in only four cases out of 30 was it over ten per cent and in only 13 over five per cent. Some of this variation might be due to irregularities in time interval as controlled by the rotating switch. However, for a given setting, the time interval did not vary more than about ± 25 microseconds which even at the lower range of time intervals would not, as shown by Figure 3, produce a variation in critical breakdown voltage of more than about two per cent. It is interesting that for intervals above 1,000 microseconds the spread of breakdown voltage for individual shots is no greater than observed when obtaining normal volt-time curves for virgin

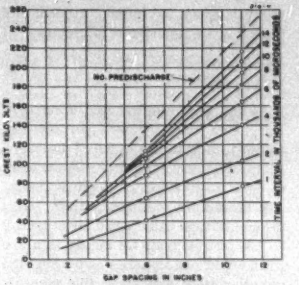


Figure 4. Critical breakdown for various time intervals as function of gap spacing

Wave C for 6-inch gap and wave I for 11-inch gap

air. This indicates that little ionization is left in the gap.

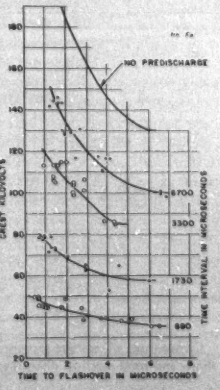
Probable Accuracy

The consistency with which the critical breakdown could be duplicated was about five per cent, and this is thought to be a conservative estimate of the probable accuracy of the curves of Figure 3. The accuracy of three points on Figure 3a for wave *D* at time intervals above 9,000 microseconds are considered questionable, because difficulty was experienced with synchronization of the trip circuits when they were obtained.

Effect of Initial Discharge Current

The curves of Figure 3 show that the critical breakdown voltage varies in a somewhat exponential manner with the time interval, increasing much more rapidly during the first 2,000 or 3,000 microseconds than thereafter. However, the maximum variation of the curves for the six-inch rod gap is remarkably small, despite the wide range of initial discharge currents. The maximum deviation from a mean occurs at the lower range of time intervals but is less than 20 per cent. After 5,000 microseconds it is less than ten per cent. Considering a mean curve for the six-inch gap, recovery to 50 per cent of the initial voltage strength occurs in about 2,500 microseconds and to 87 per cent in 13,000 microseconds. Since the deviation of the curves from one another is of the same order of magnitude as the accuracy of the data, it is difficult to determine the effect of current wave shape. As shown in Figures 2a and 3a, the higher the initial crest or the steady crest current, the lower the recovery voltage, except for the curves for waves *C* and *D*. Current magnitude appears to have more effect than charge, since some of the waves of higher initial current have much lower charge.

The manner in which the critical breakdown voltage for various time intervals increases with gap spacing is shown in Figure 4, where 6-inch and 11-inch rod-gap data for as nearly the same initial discharge current as could be reproduced are plotted. The data indicate that for any time interval the critical breakdown is approximately proportional to gap spacing. The volt-time curves of Figure 5 which are typical of those obtained show little relative flattening out with decreasing time interval. It might be expected that as the ionization remaining in the gap increases with decreasing time interval, the volt-time curves would become markedly flatter. Below about 2,000 microseconds they flatten out in regard to absolute differences in voltage but not in relative voltage change. Above



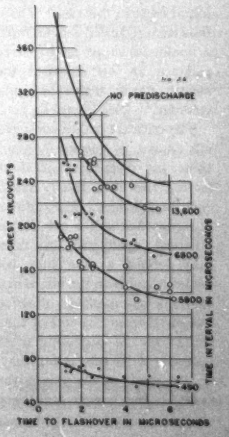


Figure 5. Volt-time curves for second voltage as applied at various time intervals

(a) (left). 6-inch rod gap

(b) (right). 11-inch rod gap

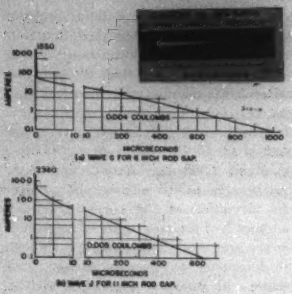


Figure 6. Wave shapes of initial discharges of long duration

3,000 microseconds the curves are approximately the same shape simply displaced in magnitude. This is further indication that little ionization is present at these time intervals.

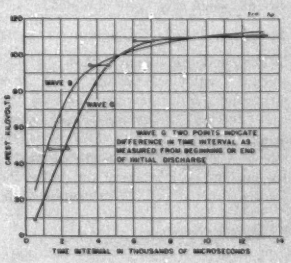
Recovery Voltages for Initial Discharges of Long Duration

The current waves of Figure 6 were produced with the surge generator of low capacity and series resistance consisting of a linear resistance in series with a number of arrester blocks. This provided a relatively low resistance at high currents but a very high resistance at low currents, thus tending to prolong the tail of the discharge. For the six-inch gap the current duration above the lower limit of recording sensitivity of 0.1 ampere is 1,000 microseconds. For the 11-inch gap it was only possible to prolong it for 600 microseconds, because more of the charge was needed in the gap at the instant of breakdown. This is shown by the higher initial crest in this case. The low current tails were recorded oscillographically with a nonlinear shunt having very high impedance at low currents and also by means of a high-speed photographic recorder.[4] (See Figure 6a.)

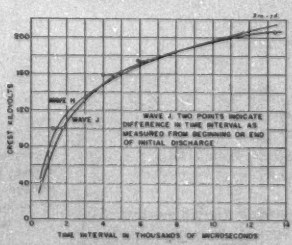
The critical breakdown curves obtained are shown in Figure 7 compared with those for discharges of short duration having the most nearly identical initial crest magnitudes. The data for the long-duration discharges are plotted for two different definitions of time interval; that defined as the time between the beginning of both the initial discharge and subsequently applied voltage and that as measured from the end of the initial discharge to the beginning of the applied voltage. It is interesting that when this shift is made in the points, they lie very close to the curves for the initial discharges of short duration except at time intervals where the initial current is still flowing at the application of voltage.

Breakdown When Current Is Still Flowing

As the time interval was lowered, it was found that although current continued to flow from the initial discharge, an appreciable voltage was still necessary in order to produce a second discharge. The breakdown was more erratic, but a definite critical value could be obtained. At 500 microseconds for the six-inch gap when about one ampere was flowing, the critical voltage was about five kilovolts and, for the 11-inch gap with about 0.4 ampere, 40 kv. The nature of the breakdown under these conditions is also interesting. Oscillograms of the two discharge currents and the second voltage are shown in Figures 8 and 9. During the period of breakdown the decrease in voltage is very gradual requiring several microseconds to drop to a relatively low voltage characterized by a fairly stable arc drop, but during the whole recorded period of voltage, it continues to decrease at a lesser rate. As higher voltages are applied, the period characterized by the more rapid drop in voltage becomes shorter until at twice the critical value it is practically instantaneous. The arc drop for the following period is also much lower, too low to record. As shown by the oscillograms of Figures 9b and 9c, the current in the second discharge rises slowly in the initial period corresponding to the slower rate of drop of voltage and increases more rapidly as the voltage drops more rapidly. The voltage and current relations are shown more clearly in Figure 10a which is a replot of Figures 9b and 9c superimposed. The character of the discharge current is quite different under these conditions than for normal breakdown. In the latter case, the path is first made partially conducting by initial leaders before the breakdown is completed by the return streamer process, which results in a high instantaneous flow of current and practically instantaneous drop in voltage. In this case, however, where considerable ionization exists because of the small flow of current, the transition from the low-conducting to high-conducting conditions is more gradual and uniform. The initial crest current characterizing the final breakdown of the gap is less pronounced and of longer duration. Comparison of the current in the second discharges of Figures 8 and 9 shows that


CREST KILOVOLTS
WAVE B
WAVE G
WAVE G TWO POINTS INDICATE DIFFERENCE IN TIME INTERVAL AS MEASURED FROM BEGINNING OR END OF INITIAL DISCHARGE
TIME INTERVAL IN THOUSANDS OF MICROSECONDS

(a). 6-inch rod gap


CREST KILOVOLTS
WAVE H
WAVE J
WAVE J TWO POINTS INDICATE DIFFERENCE IN TIME INTERVAL AS MEASURED FROM BEGINNING OR END OF INITIAL DISCHARGE
TIME INTERVAL IN THOUSANDS OF MICROSECONDS

(b). 11-inch rod gap

Figure 7. Comparison of voltage-recovery curves for short- and long-duration discharges

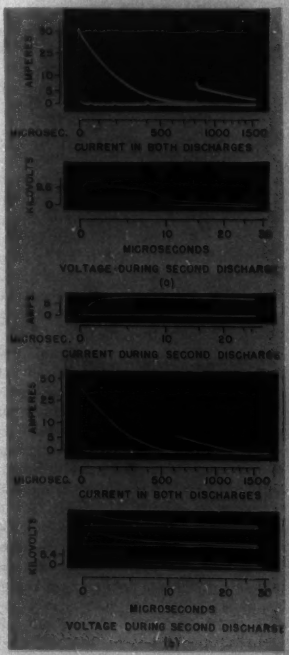


Figure 8. Current and voltage oscillograms when initial discharge is of long duration

6-inch rod gap. Wave G of Figure 6a

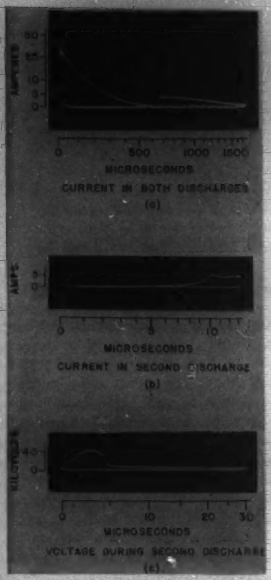


Figure 9. Current and voltage oscillograms when initial discharge is of long duration

11-inch rod gap. Wave *J* of Figure 6b

this initial crest increases with the time interval between discharges. The gradual transition of the arc path may have been influenced by the character of the voltage surge-generator circuit. The series resistance had to be fairly high, since only a small fraction of the potentiometer could be tapped off in producing the low discharge voltages. This could have produced appreciable regulation.

A measure of the effective impedance of the arc during the various stages can be obtained by determining the "effective" resistance from the current and voltage oscillograms. Such data are shown in Figure 10b. Synchronized simultaneous records were not obtained for each discharge; however, as shown by Figure 8b, the results could be duplicated with a good degree of consistency. It was found that for the initial discharges of Figure 6 the steady crest magnitude of the current in the second discharge was about five amperes for both gap spacings and essentially constant for a variation of time interval of as great as 300 microseconds. The arc resistance is, of course, quite high before the start of the second discharge, decreasing to about 1,800 ohms per foot for the 11-inch gap and 1,200 ohms per foot for the six-inch gap at the peak of the discharge current. Then it decreases more gradually. At the end of about 20 microseconds it is reduced by about 50 per cent. It is of interest to compare the arc under these transient conditions with that of stable arcs. After the arc has been established at the crest of the discharge current, the arc drop is about 9,000 volts per foot for the 11-inch gap and 6,000 volts per foot for the 6-inch gap. Although it is decreasing rapidly, it has not at the end of 20 microseconds dropped to anywhere near the normal value of 400 or 500 volts per foot, which is typical of steady-state conditions for arc currents of this magnitude.[5]

Photographic Study of the Arc Path

Photographic studies were made of the arc path by means of the high speed rotating camera and two still cameras mounted so as to photograph the arc from directions 90 degrees apart. Typical records are shown in Figure 11. About 250 microseconds is the shortest time interval for which a record could be obtained because the arc luminosity was too low to photograph for the very small currents resulting in the second discharge. As shown in Figure 11a, the path of the second discharge is not identical with that of the first for times as short as 250 microseconds. It diverges more and more as this time interval is increased. Up to about 2,000 microseconds the second discharge maintains the major bends of the first, but after about 5,000 or 6,000 microseconds it has departed entirely from the characteristics of the original path. Figures 11a and 11b show the second arc path to be more tortuous than the first. As shown by the sets of two still photographs, the second discharge follows a more or less winding path in a given cylindrical volume of air surrounding the original path, the radius of which increases with time as this volume of air with lower dielectric strength expands.

In Figure 12 an attempt was made to show the divergence of the two paths as a function of time. On this curve are plotted points representing the average of at least five records of the maximum three dimensional divergence of any part of the second arch path from the first. These data were obtained from simultaneous photographs taken with the two still cameras. For the short-duration discharges, divergence is more or less independent of the character of the initial discharge or of the gap spacing, and all the points lie close to a single curve for time intervals up to about 7,000 microseconds. After this, they diverge widely. For the long-duration discharges the divergence, when plotted as a function of time interval after the end of the first discharge, also conforms closely to the same mean curve except for the point at lowest time interval, for which current is still flowing. Then, although the arc path is still conducting current, the subsequent path blazed by the second discharge is not identical with that of the first which, as photographed, is probably the arc path formed during the initial high current portion of the discharge. During the longer period in which the lower current magnitude exists, the conducting core is expanding radially, and the current density is probably greatly decreased. This may contribute to some extent to the appreciable critical voltages when current is still flowing.

Mechanism of Recovery

The curve of Figure 12 gives a measure of the rate at which the conditions of low dielectric strength set up by the discharge in the arc path are expanding radially. The two principal conditions which may be contributing to the lower dielectric strength of this expanding region are high temperature and ionization. Both effects will propagate radially into successively larger volumes of air. As this heat and ion diffusion takes place, together with ion neutralization by recombination, the dielectric strength of the air should increase. Since both of these conditions are so interconnected, it has always been difficult to separate them for study. Browne,[6] however, has obtained data indicating that the ionization effect cannot be appreciable after the first 100 microseconds for short a-c arcs between

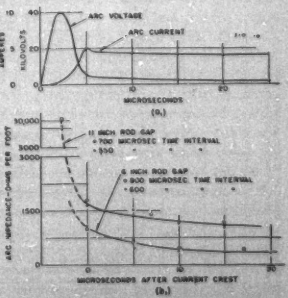


Figure 10. Voltage and current characteristic of discharges produced before or shortly after end of initial discharge

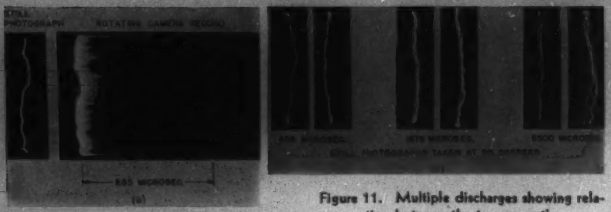


Figure 11. Multiple discharges showing relation between the two arc paths

11-inch rod gap

(a), (b). Wave *I* of Figure 2b
(c). Wave *H* of Figure 2b

parallel brass electrodes. Although this condition is quite different than for long arcs where electrode effects are much less, the consistency of breakdown and the character of the volt-time curves lead one to suspect that the temperature effect is also predominant for long arcs and short surges, at least for time intervals above 1,000 microseconds.

It is realized that turbulence and other factors insufficiently known by the authors make an analytical study of the problem difficult. However, some very approximate calculations have been made of temperature variation with time. Curve *A* of Figure 13 is a mean curve for the rate of voltage recovery of the six-inch rod gap. Curve *B* is a plot of temperature variation with time determined from curve *A* on the assumption of constant pressure throughout the air column and thus, that the dielectric strength of the air is inversely proportional to temperature. The starting point for the calculation was the critical breakdown voltage at normal room temperature. It is interesting that such a curve gives temperatures at the lower range of time intervals that correspond to those normal for arcs.

Any attempt at a rigorous calculation of rate of ion or temperature diffusion could not account for turbulence and would always give the highest ion density or temperature at the original arc core. Thus, successive discharges should always follow the same path blazed by the first. Such calculations for heat diffusion, assuming cylindrical symmetry and constant gas density, specific heat, and thermal conductivity, indicate rates of temperature drop of the same order of magnitude as given by curve *B* of Figure 13, but somewhat more rapid. It is probably the extreme condition of turbulence which produces localized regions of low dielectric strength of a more or less random distribution throughout a certain region whose radius is given by Figure 12.

Because of this, it was thought that perhaps the only analysis which was warranted was merely the very crude one based on the assumption that the heat produced in the original arc column resides at any time interval in a cylindrical column of air given by the radius of Figure 12 for that time interval and that the temperature in the column is uniform. Curve *C* of Figure 13 was calculated on this basis, starting with a temperature of 4,000 degrees Kelvin and a radius of 0.13 inch at a time interval of 250 microseconds. It conforms quite closely to curve *B*. This is not necessarily confirmation of the accuracy of either curve, but it is believed to indicate that the temperature of the air column alone can account for the rate of voltage recovery.

Mechanism of Natural Lightning

Photographs of natural lightning taken with the Boys camera or similar devices imparting the time element to the record indicate that all components of a multiple stroke follow the same path except in rare cases when a component discharge will follow the original path part way to earth, then depart entirely from it. A record of a typical multiple stroke obtained in the Westinghouse investigation is shown in Figure 14. However, deviation of a fraction of an inch or even several inches cannot be distinguished on such records and probably do exist.

The rates of voltage recovery which have been obtained indicate that the time intervals between components can be high enough (ranging from 0.0005 to 0.5 second[9]) that, unless low current flows for an appreciable portion of the intervening period, the subsequent discharge should not always follow the same path. From evidence provided by strokes to very tall objects, Bruce and Golde[10] have concluded that current must flow continuously between components. However, four records have been obtained with the photographic surge-current recorder[4] of multiple strokes to low objects. Two of these records are shown in Figure 15. This device is capable of measuring currents as low as 0.1 ampere, and for all of the records there is an appreciable period between at least two components in which

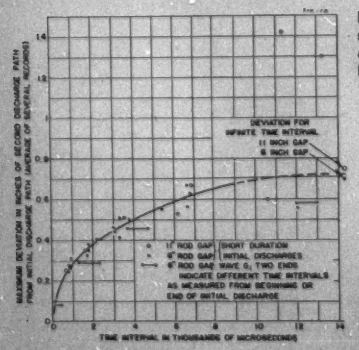

DEVIATION FOR INFINITE TIME INTERVAL
11 INCH GAP
6 INCH GAP
12" ROD GAP
6" ROD GAP
6" ROD GAP WAVE G, TWO ENDS INDICATE DIFFERENT TIME INTERVALS AS MEASURED FROM BEGINNING OR END OF INITIAL DISCHARGE
SHORT DURATION INITIAL DISCHARGES
TIME INTERVAL IN THOUSANDS OF MICROSECONDS

Figure 12 (left). Curve showing variation of second arc from initial arc path as function of time interval between discharges

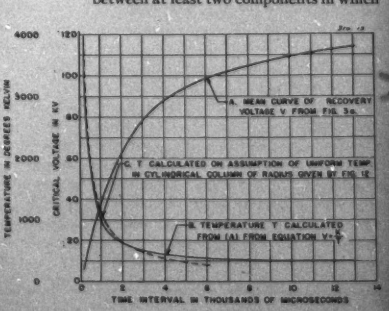

A. MEAN CURVE OF RECOVERY VOLTAGE V FROM FIG. 3a
C. T CALCULATED ON ASSUMPTION OF UNIFORM TEMP IN CYLINDRICAL COLUMN OF RADIUS GIVEN BY FIG. 12
B. TEMPERATURE T CALCULATED FROM (A) FROM EQUATION V=
CRITICAL VOLTAGE IN KV
TEMPERATURE IN DEGREES KELVIN
TIME INTERVAL IN THOUSANDS OF MICROSECONDS

Figure 13 (right). Calculated curves of variation of arc-path temperature with time after initial discharge

Figure 14. Record of multiple stroke to open ground

no current was measured. It is interesting that none of these periods has exceeded about 23,000 microseconds. The extrapolated voltage-recovery curves of Figure 3b indicate that, for stroke currents of the general character studied, 30,000 to 40,000 microseconds should be about the upper time-interval limit for zero current between successive components. Otherwise, the dielectric strength of the original stroke channel will have sufficiently recovered that the subsequent discharge might take a totally different path. However, some of the strokes which have been measured[9] have continuing currents of such high magnitude and duration that their rate of recovery may be appreciably lower.

Records of strokes, such as Figure 14, show extreme fluctuations of luminosity as a characteristic condition in the stroke channel. The long-duration stroke component in Figure 15 shows a similar wide range of fluctuation of current which is probably associated with such luminosity variations.

Comparison With Rate of Dielectric Recovery for Power Arcs

The rapid rate of recovery and small dependence on current magnitude for surges of short duration are in considerable variance with results that have been found for power arcs. Rates of recovery for 60-cycle arcs have been determined only for very short gaps (one to ten millimeters) where electrode effects and field considerations are quite different.[6,7] These data for currents of the order of five to ten amperes show rates of recovery as rapid as those for short-duration surges. However, as the power current is increased, the rate of recovery drops rapidly. For currents above 100 amperes such data indicate that an appreciable fraction of a second is required for recovery to anywhere near the original strength of the gap.

Evidence that this is also the case for long arcs is provided by tests of Griscom and Torok[8] in which the probability of restriking was determined for gap spacings of the order of 10 to 100 inches. Arcs with currents ranging from 800 to 1,500 amperes were started with fuse wire and allowed to continue for a period of about nine cycles, which should have been sufficient to eliminate the effect of the vaporized wire. The arc was interrupted and voltage reapplied after various time intervals to determine the probability of restriking. The voltages were those of transmission lines with conductor spacings equal to the gap spacings and were thus about 25 per cent of the normal gap breakdown voltage. Nevertheless, the probability of restriking was found to be appreciable for periods as long as five or six cycles.

Except for the time element introduced by multiple strokes of appreciable duration, the character of the power-follow current, since it produces such slower rates of recovery than the initiating lightning flashover, should be the principal factor governing circuit-reclosing times. Reclosing times should thus be based on the probability of the duration of multiple strokes[9] and the probability of restriking for power arcs.

Probability of Lightning Flashover Producing Power Follow

The high rate of dielectric recovery for surge-current discharges in air gaps suggests that, for lines where flashover will occur in air at atmospheric pressure, an appreciable percentage of the flashovers that do not cause an outage may be lightning flashovers that produce a disturbance of very short duration. That this is the case is shown by an analysis of system recovery voltage conditions for lightning flashover. Stroke components of sufficiently short duration can cause flashover on a certain portion of the normal conductor voltage cycles and produce a current zero occurring in a relatively short time. The current flow in the gap will be such that the rates of dielectric recovery are comparable to those of Figure 3 and lying above the system recovery volt-time curve.

There are two conditions for which such rapid arc extinction will occur. The first of these is illustrated in Figure 16a for which the lightning flashover occurs at a time (T) before and close to the time of normal zero system voltage. If the duration the of lightning discharge were negligible, the fundamental-frequency fault current would have, as shown in Figure 16a, an initially low magnitude followed quickly by a current zero. The magnitude and duration of this current and the magnitude of the fault recovery voltage increase with the time (T). The recovery voltage curves as a function of (T) have been determined with the a-c network calculator[11] for a typical simple system having a natural frequency of 1,000 cycles per second. This corresponds to about a 40-mile line. The system recovery voltage curves are shown in Figure 16b compared with the dielectric-recovery curves for two ratios of insulation level to normal crest system voltage, four times normal and six times normal. As shown by this figure, the maximum time T for which the system recovery curve lies below the dielectric-recovery curve is about 1,100 and 1,700 microseconds for the respective insulation levels. This condition can be produced by stroke currents with polarity either the same or opposite to the initial normal frequency fault current. It can thus occur on either half-cycle. If the duration of the lightning discharge does not tend to shift the normal current zero, these recovery curves can be applied to surges of appreciable duration. A calculation of the probability of flashovers not producing power follow was made on the conservative assumptions that they could be produced by single-component strokes only, having durations less than the time from the instant of flashover to the time of normal-frequency current zero. With the data available on the probability of multiple strokes and stroke-component durations[9] such an analysis indicates probabilities of flashovers not producing power follow of five and nine per cent.

Lightning flashover occurring shortly after normal system voltage zero will produce a current zero in a short time if it is the opposite polarity to the normal-frequency fault current. Thus on the assumption that strokes are predominantly negative there is a certain period on every other half-cycle when this condition can take place. Neglecting the effect of the initiating transient, the system recovery voltage curve, as a function of the time of current zero after normal system voltage zero can be estimated for this case by considering its crest to be twice the normal system voltage at the instant of current zero. It reaches crest in 500 microseconds for the system considered. Such an assumption indicates that the percentage of strokes which will not produce power follow are three and five, respectively, for the two insulation levels. This gives a total of 8 and 14 per cent of strokes causing flashover with disturbances of only short duration. The

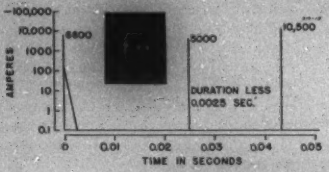


Figure 15 (left). Current in multiple lightning strokes to 85-foot fire towers as obtained with photographic surge-current recorder[4]

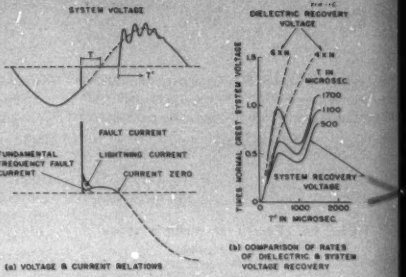
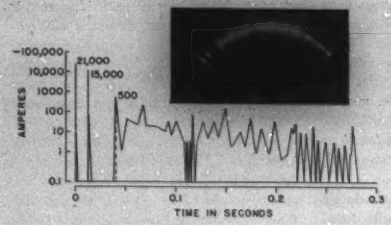


Figure 16 (right). Condition for lightning flashover on transmission line causing only short-duration disturbance

Dielectric - recovery curves obtained from Figure 3. $4 \times N$ represents air-gap insulation level four times normal crest system voltage



probability of rapid arc extinction will increase with the ratio of the insulation level of the line to the line voltage and with the length of the line or reduction in its natural frequency.

Data[13] have been obtained showing the percentage of system disturbances whose duration is one cycle or less. These data show an average of about eight per cent of such disturbances for steel tower lines and about 20 per cent for wood-pole lines. These short-duration disturbances are probably of the nature of those discussed above. Good agreement is shown for steel lines where the flashover path is confined entirely to air. The higher percentage for wood-pole lines confirms other data indicating that wood insulation has greater extinguishing power than air alone. Additional data[3] available on the ratio of flashovers to outages on steel tower lines indicate a range of from 15 to 35 per cent for the proportion of total flashovers not producing outages. Thus it is indicated that about half of the flashovers not causing a fault are these very short-duration disturbances.

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Mercury-Arc Rectifiers.—Bulletin GEA-3827, 28 pp. "Ignitron Mercury-Arc Rectifiers in the Steel Industry." Outlines various conversion-equipment problems in the steel industry, and discusses the characteristics and the various applications of ignitron mercury-arc rectifiers in meeting these problems. Among the subjects discussed in the bulletin in reference to steel mills are d-c power supply, d-c systems, 250-volt distribution systems, 600-volt continuous mill systems, and reversing mill systems. General Electric Co., Schenectady, N. Y.

A-C Welders.—Bulletin B-3136, 12 pp. Describes a complete line of Flexarc a-c welders, with current ratings from 100 to 500 amperes. Features are the 500 ampere industrial welder for high-speed, continuous welding on all types of heavy construction; and the 300-ampere portable welder for heavy-duty work. Both models have built-in power-factor correction. The booklet compares advantages of a-c and d-c welding. Speed is said to be increased 20 to 30 per cent and power costs cut one-third with the flexarc a-c welders. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

High Frequency Heating Equipment.—Booklet. Describes complete Thermex equipment for drying and bonding of woods, plastics, chemicals, fibrous matter and other non-conducting materials. It answers many of the questions and problems usually presented in connection with this interesting new development. Proved advantages in speed and efficiency of bonding or drying are described. Potential applications are cited, with comments on past experiments in related fields. This booklet makes it easy to understand the advanced principles involved in high frequency electrostatic heating. The Girdler Corporation, Thermex Div., 224 East Broadway, Louisville, Ky.

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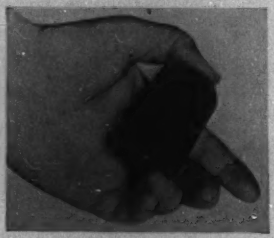
NEW PRODUCTS

Wire Insulation Remover.—A rotary wire brush whose surface is as soft to the touch as the nap of a velvet rug, has been developed by the Osborn Manufacturing Co., 5401 Hamilton Ave., Cleveland, Ohio, to remove insulation from copper wires. The brush, in the form of a cylinder, $1^1/_2$ inches in diameter and 2 inches long, is made of mild steel wire .0025 inch thick. The wire in the brush is so fine and so closely packed



that there are nearly a quarter of a million points over the surface area. The brush surface is as soft as velvet, although each point is as sharp as a needle. Two of these cylinders, mounted parallel and rotating on spindles at 3,450 revolutions or more per minute, were developed to trim very hard-baked insulation off exceptionally fine copper wire used in electrical instruments without marring the copper underneath. The insulation is taken off as rapidly as the operator can insert the wire between the rotating cylinders and pull it out. The problem of taking off insulation from wires of a wide variety and size has been made a highly simplified operation. The brushes are mounted on spindles arranged so that they run parallel in order to clean entirely around the wire. The proximity of the brush surfaces is determined by the job to be done. Each brush may be mounted on a motor, or one motor may be used for both. The rotary speed of the brushes varies with the insulation and the size of wire being stripped. The gauge of the wire in the brush is determined by the amount of scoring permitted on the wire being cleaned. When the electric resistance of the conductor is very carefully calculated, even a very small amount of scoring is not allowed.

Acetate Fabric Tape.—Introduced by the Industrial Textile Division, Wm. E. Wright & Sons Co., West Warren, Mass., "KAPPA" electrical insulating tape is a woven cellulose acetate material which is said to have demonstrated marked superiority over tapes previously available, both in electrical characteristics and in winding and varnishing procedures. The new product has substantially higher dielectric strength of insulation as compared to cotton tapes. For total thickness up to approximately 10 mils (fabric plus varnish) the breakdown voltage of the varnished KAPPA tape is of the order of 50 percent higher. Varnished samples maintained flexibility during baking at 125 degrees centigrade for 60 percent longer period, thus indicating longer insulation life. Considerably less hygroscopic than cotton under general conditions, KAPPA tape has a moisture regain less than one-half that of cotton. Its construction was designed to allow ample tensile strength (47 lb per in.—7.0 percent elongation), and to facilitate winding production. Prominent manufacturers of major electric equipment using this new tape report—(1) "It handles very much better in winding machines and hand applications, producing smoother and more even windings." (2) "Varnish applies more uniformly providing better surface." (3) "KAPPA wound coils use less varnish and after impregnation show higher dielectric strength." (4) "One varnish dip and baking can be eliminated still retaining considerably higher dielectric strength." Prices are at cotton levels on some widths. Readily available in 3, 5, 7 and 10 mil thicknesses and widths $^1/_4$ inch up. Samples and engineering data are available on request to manufacturer.

Circuit-Testing By-Pass for Street-Lighting Cutouts.—A circuit-testing device for Novalux loop-sectionalizing cutouts equipped with a Thyrite by-pass, has been announced by the lighting division of the General Electric Co., Schenectady, N. Y. The testing by-pass is equipped with an SL-type film cutout, which provides a quick and inexpensive means of testing circuits. This device enables the service man to determine whether the circuit is actually closed before installing a new Thyrite by-pass. If an open-circuit causes the cutout to trip out, the circuit is repaired and the testing by-pass is inserted before the Thyrite by-pass is put into place. The circuit-testing by-pass is not intended as a substitute for the Thyrite by-pass. Unlike the Thyrite device, the film cutout is unable to differentiate between a surge voltage such as that caused by lightning and a sustained overvoltage caused by an open-circuit. The illustration shows a film cutout being inserted in a circuit-testing by-pass used for testing loop-sectionalizing cutout circuits before the Thyrite by-pass is inserted.

Immersion-Proof Control Switch.—This heavy-duty, immersion-proof control, instrument or transfer switch developed by the Delta-Star Electric Co., 2400 Block, Fulton St., Chicago, Ill., is rated 20 amperes, 600 volts a-c, with four-circuit control. Turning the handle to right or left

closes a circuit; pushing in handle opens third circuit and pulling out handle opens fourth. A spring return restores to normal conditions by releasing handle after operation. Locking features in the handle design permit locking in either the normal or pushed-in position.

Combination Insulator and Wire Marker.—Short lengths of extruded plastic tubing are clearly marked with letters and numerals to perform two jobs. They serve as insulators of terminal connections and as wire markers. Where lug insulation and wire identification are required, they speed assembly by elimi-

nating any additional means of identification. The tubing from which these new combination insulator markers are made has very high dielectric strength. Smooth inside surfaces permit quick application over wires and lugs. Legible numerals as desired are printed on the tubing with an ink that has resistance to chemicals, water and oils equal to that of the tubing itself. Available in colored tubing with either black or yellow symbols, in ASTM sizes from No. 9 up to $^3/_8$ inch, inside diameter, or even larger. Other tubing made from much less critical plastic materials can be printed and utilized solely as wire markers. Introduced by the Irvington Varnish & Insulator Co., Irvington, N. J.

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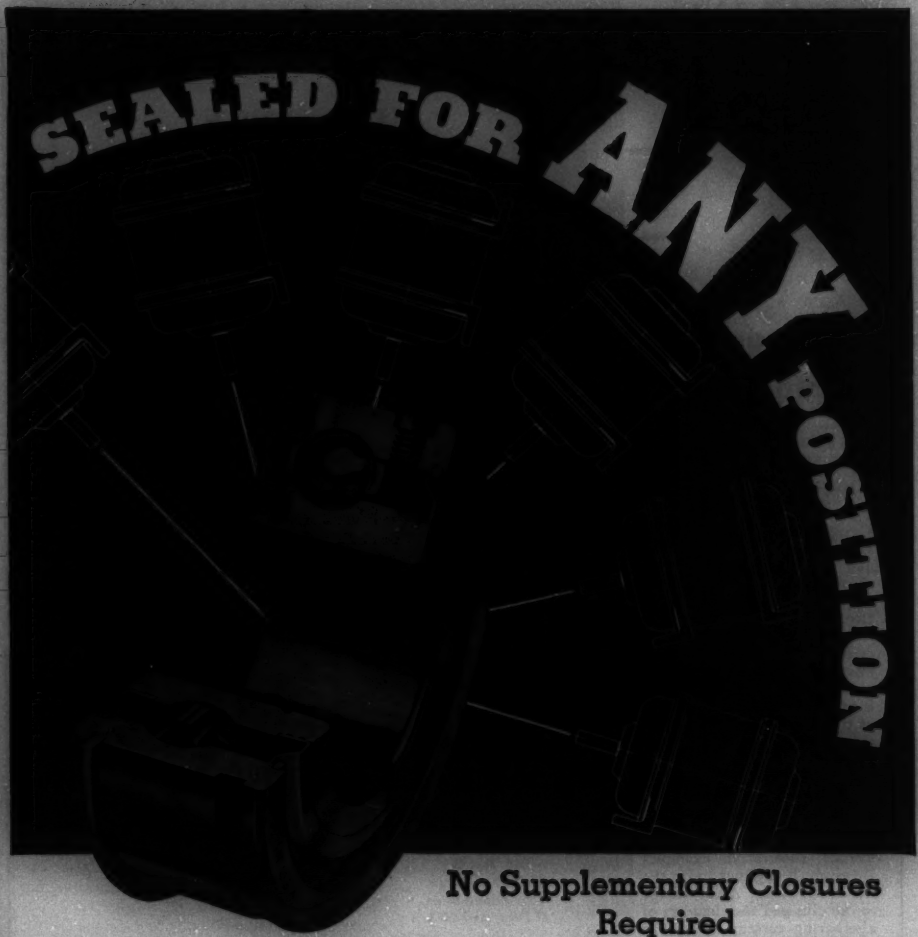

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Sec. No. 45 AIEE Standards With Addenda as of February 1942

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These rules have been drawn up to serve as a guide for the equipment of merchant ships with electrical apparatus for lighting, signaling, communication, power and propulsion for both alternating and direct current systems. They indicate what is considered good engineering practise with reference to safety of the personnel and of the ship itself, as well as reliability and durability of the electrical apparatus.

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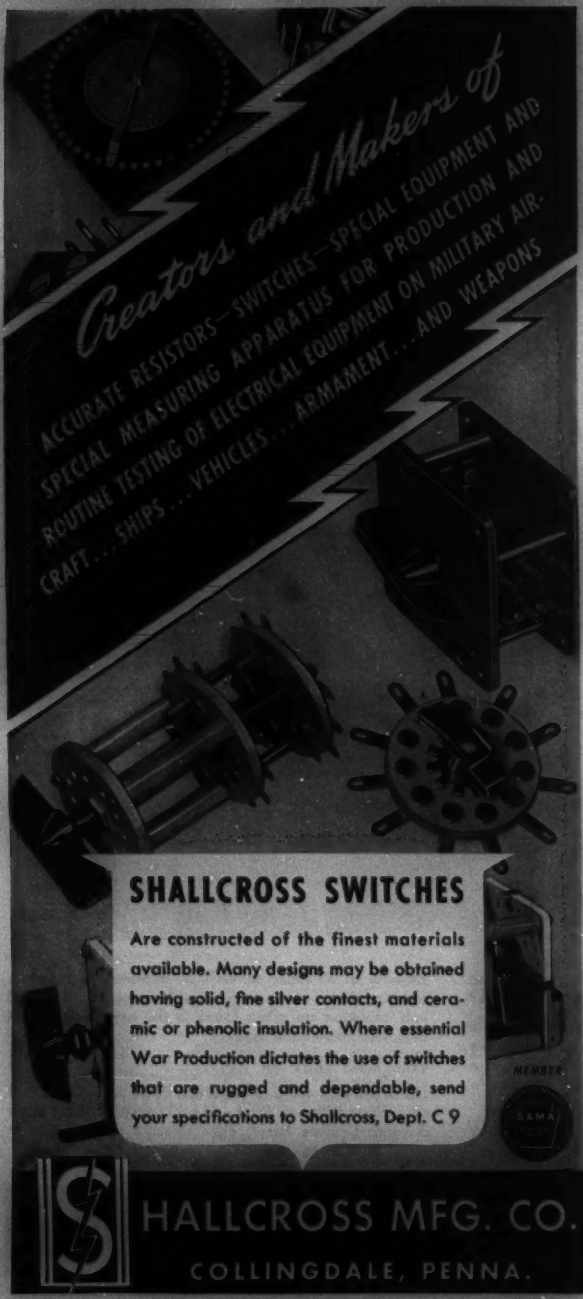
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Following the arrangement of the "Bibliography of Relay Literature, 1927–1929," published in July 1941, the reference items in the "Bibliography on Circuit-Interrupting Devices" are divided according to subject, and within each section are numbered consecutively, subdivided by years, and listed alphabetically for each year. The subject headings are: Circuit Breakers (Air, Oil, Water, Rapid Reclosing, Recovery Voltages, General and Miscellaneous), Enclosed Switchgear, Air Switches, Bus Bars, and Fuses and Fuse Protection.

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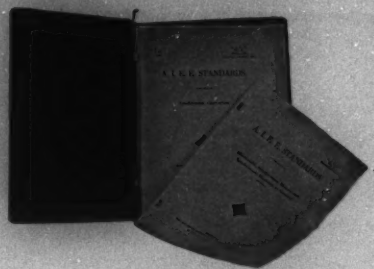

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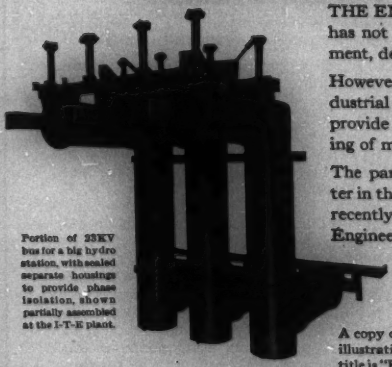

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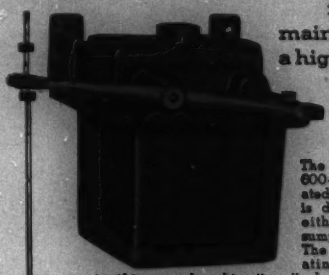

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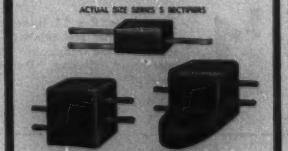

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Universal Clay Prod. Co., Sandusky, O.

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POWDER METALLURGY (MOLDED)
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General Electric Co., Schenectady, N. Y.
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General Radio Co., Cambridge, Mass.
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Sola Electric Co., Chicago, Ill.
Westinghouse E. & M. Co., E. Pittsburgh

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(*Continued on page 36*)

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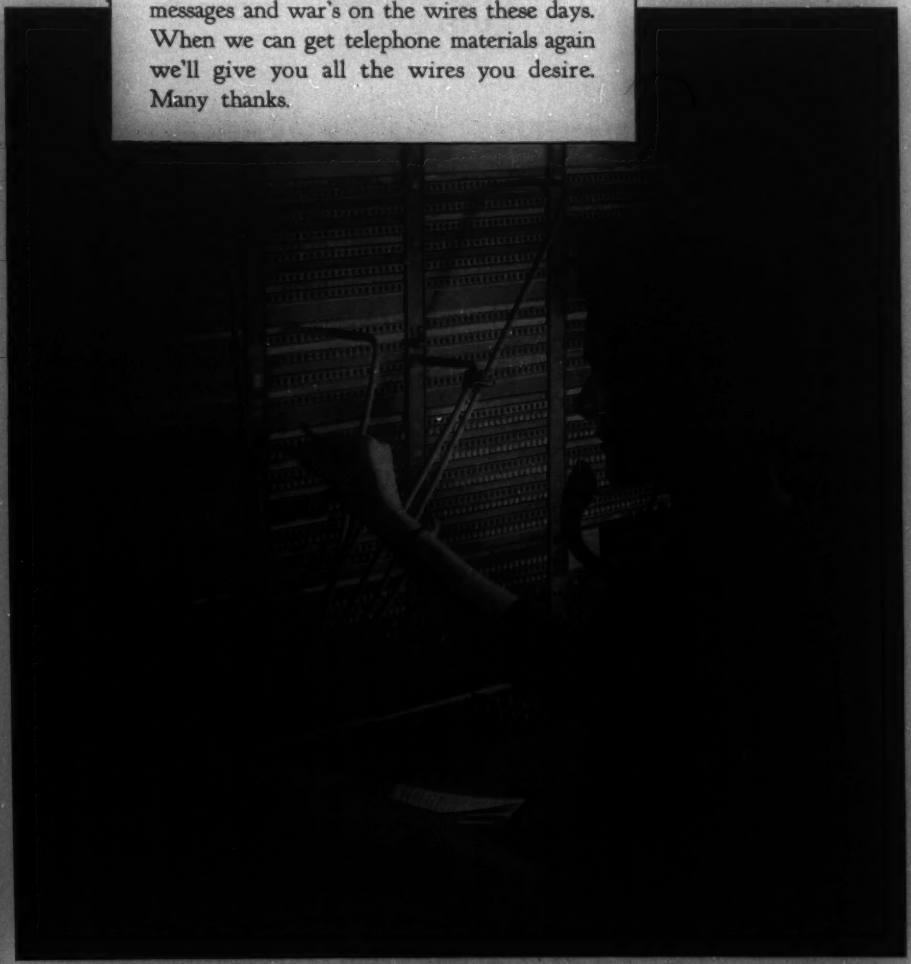
"Please do not make Long Distance telephone calls to war-busy centers unless it is really necessary."

That helps keep the lines open for war messages and war's on the wires these days. When we can get telephone materials again we'll give you all the wires you desire. Many thanks.



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Write today for technical data sheets. Give details of your problem so that our engineers can be of help. There is no cost or obligation.

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International Resistance Co., Philadelphia
Ohmite Mfg. Co., Chicago
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SEALS
Armstrong Cork Co., Lancaster, Pa.

SHEET METAL PRODUCTS
Kirk & Blum Mfg. Co., The, Cincinnati

STANDARDS, RESISTANCE
Shallcross Mfg. Co., Collingdale, Pa.

STEEL, ELECTRICAL
Allegheny Ludlum Steel Corp., Pittsburgh

SWITCHBOARDS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
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SWITCHES, ROTARY SELECTOR
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Mineralac Electric Co., Chicago

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Westinghouse E. & M. Co., E. Pittsburgh

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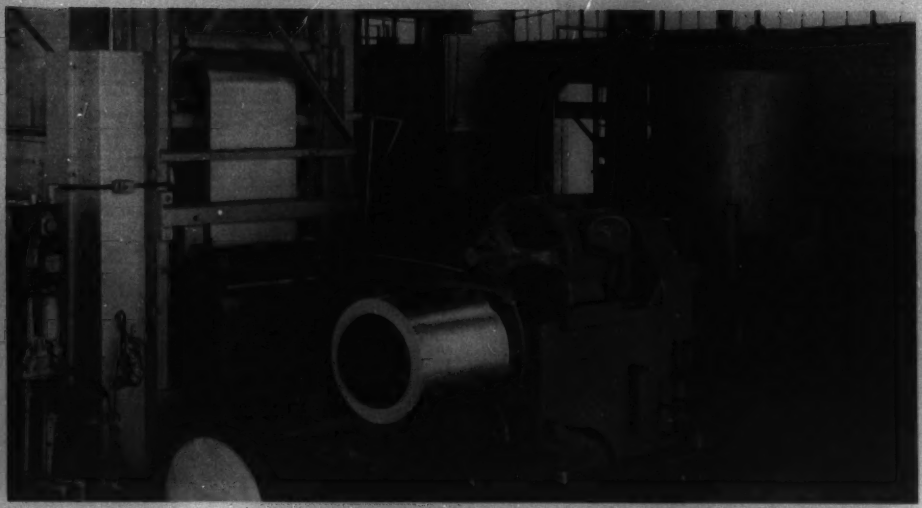


Photo courtesy of the Crown Cork & Seal Company

The best news about tin since we went to war

WHEN the Japs overran Malaya and the East Indies, they thought they had dealt a staggering blow to America.

For, overnight, tin became a most critical raw material, because America relies upon this bright metal for tin plate, bearing alloys, solder, collapsible tubes . . . *but mostly tin plate.*

However, Uncle Sam had an ace in the hole . . . *electrolytic tin plate.* In this process tin is deposited electrolytically on steel strip. And only *one third* the tin used in the old hot-dipped process is required.

Unfortunately, electrolytic tin plate is far from perfect as it comes from the plating baths. It is porous and does not provide a good protective coating.

Right here Westinghouse stepped into the picture.

Engineers in the Westinghouse Research Laboratories decided that the porous tin coating could be *fused* . . . through the magic of electronics . . . to give the tin plate the desired protective coating.

These scientists built a high-frequency coil, using radio broadcasting oscillator tubes for their power source. Through this coil they passed electrolytic tin plate. The inductive heating effect melted the tin coating . . . refining it and giving it the necessary corrosion-resistant properties.

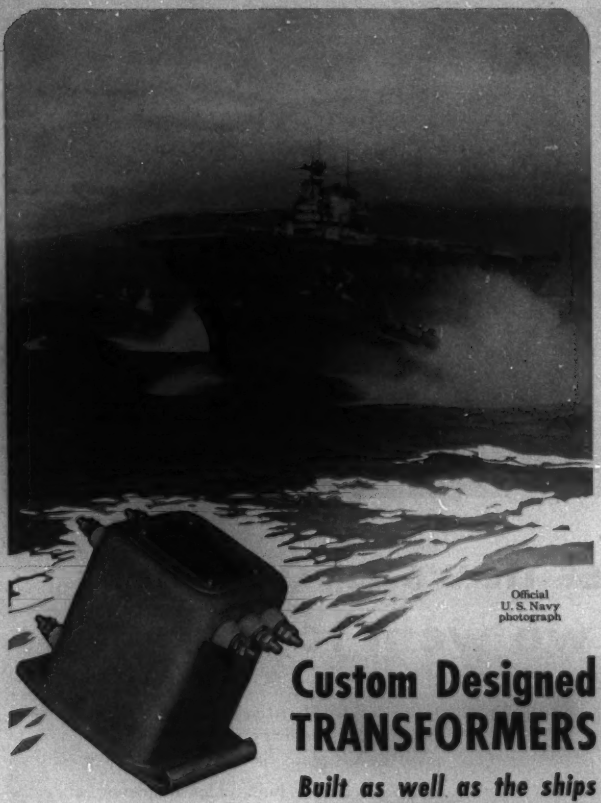
The new Westinghouse tin flowing process is now in actual use, turning out gleaming ribbons of tin plate at better than 500 feet per minute. It will help save thousands of tons of tin every year.

Another example of *electronics at work* . . . through Westinghouse "know how"!

Westinghouse Electric & Manufacturing Company, Pittsburgh, Pennsylvania.

Westinghouse

PLANTS IN 25 CITIES . . . OFFICES EVERYWHERE



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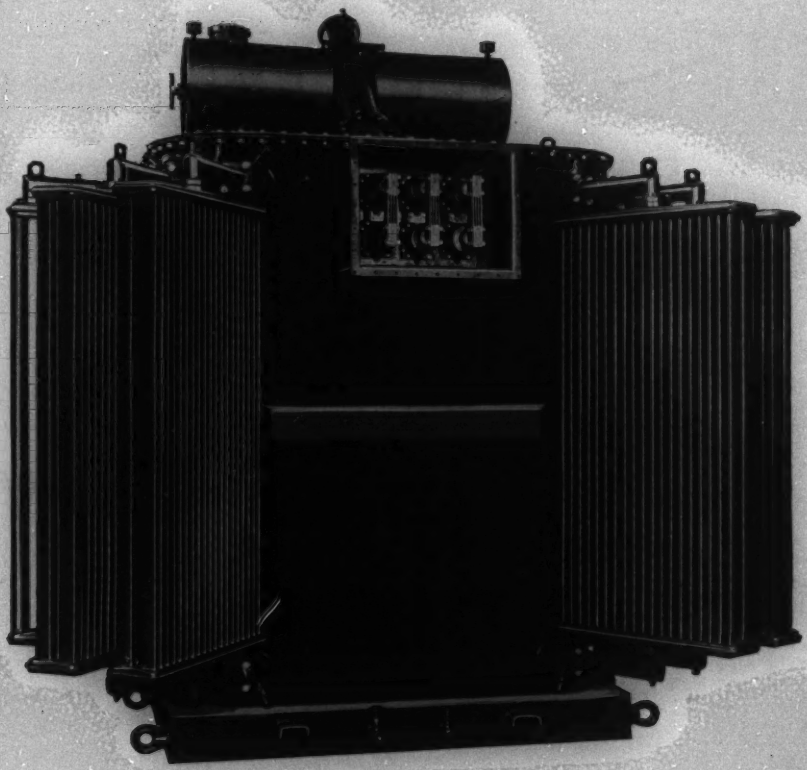

Kuhlman Power Transformers withstand the stress and strain of constant heavy duty

In these days when power-line dependability is so important it is reassuring to have Kuhlman Power Transformers on the job. For in these powerful units is incorporated every construction detail that modern engineering can devise to increase strength and ruggedness. Cores and coils are effectively braced against mechanical distortion. Long bridges prevent wire breakage due to vibration. End-coils are reinforced to prevent failure from surge potentials. Tap changers and tap leads, frame and case, in fact, each component part of these sturdy power transformers is of extra-heavy construction.

Records of installations from coast to coast reveal that Kuhlman Transformers have what it takes to withstand the stress and strain of constant heavy service with a minimum of maintenance.

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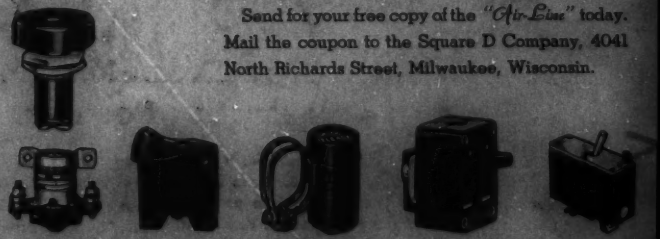

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